SPACE SCIENCES

07 March 2012

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Program Manager

AFOSR/RSE

Integrity ★ Service ★ Excellence

Air Force Research Laboratory

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2012 AFOSR SPRING REVIEW
Space Sciences Portfolio Overview

NAME: **Dr. Cassandra Fesen**

BRIEF DESCRIPTION OF PORTFOLIO:

Specifying and forecasting the geospace environment of Earth, extending from the Sun to the Earth's upper atmosphere, for Situational Awareness and for Space Control

SUB-AREAS IN PORTFOLIO:

Solar and Heliospheric Physics
Magnetospheric Physics
Ionospheric and Thermospheric Physics

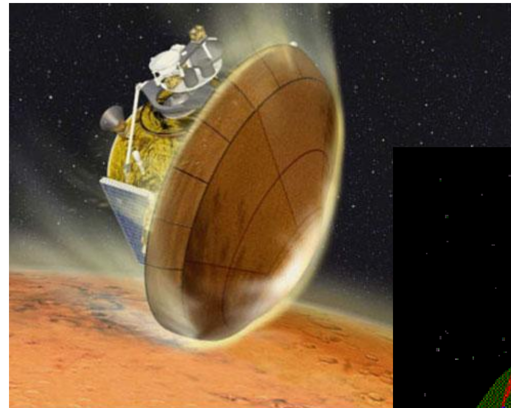
Space Weather

Outline

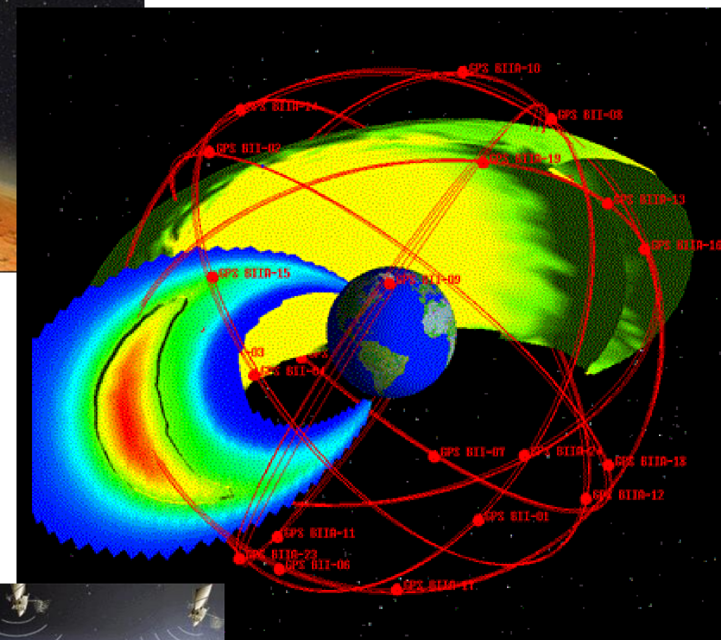
- **Why the AF has a Space Sciences program**
  - What parts of Earth's atmosphere are of interest
- **What are some projects in Space Sciences**
  - Solar investigations
  - Radiation belt investigations
  - Thermosphere / Ionosphere investigations
- **Wrap-up**
  - What are the trends
  - What other agencies are working in this area

Why the Air Force interest in Space Sciences?
Space Weather

Space Weather effects include:

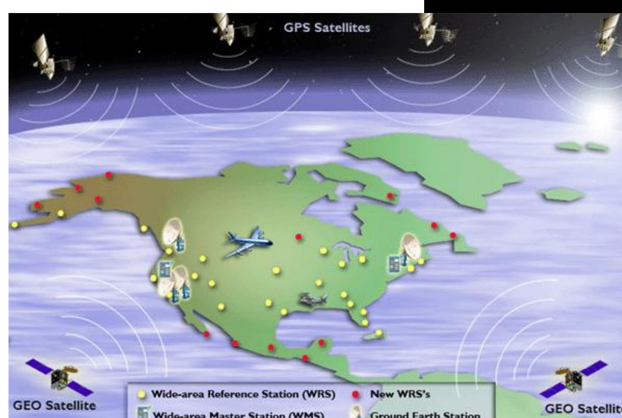


- satellite drag



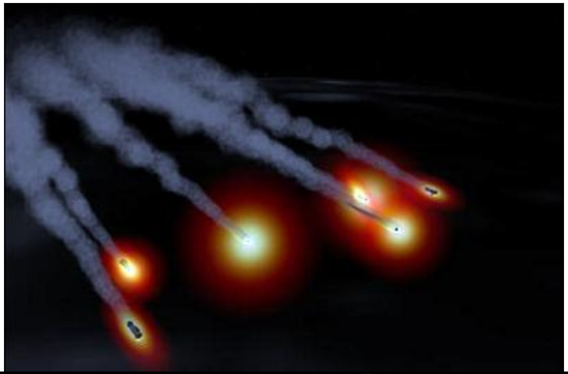
- radiation belt perturbations

- communication/ navigation/ surveillance



Space Weather effects: Satellite Drag

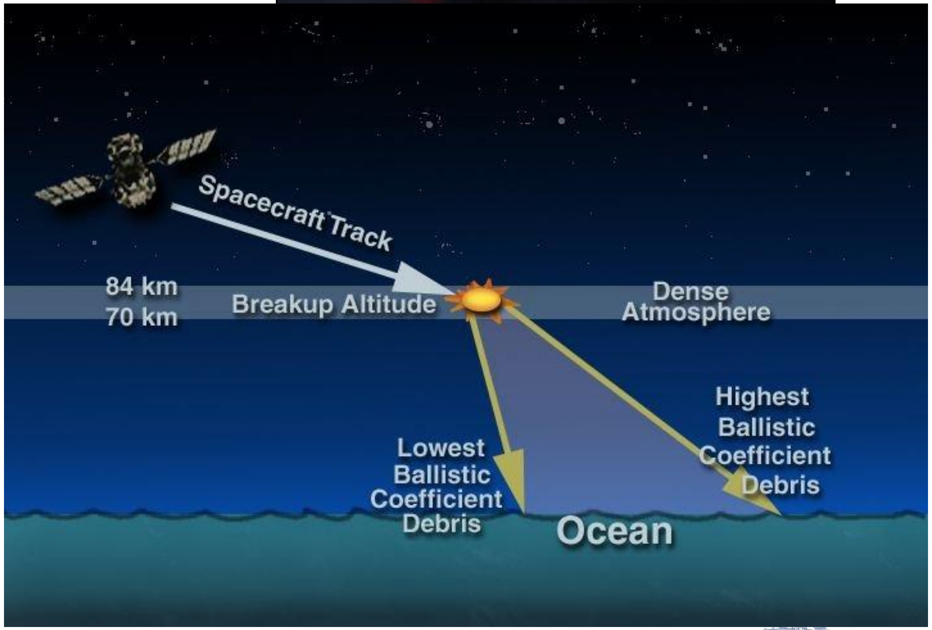
AFSPC* has a 72-hour prediction requirement for neutral densities



Because of the direct impact on satellite drag → orbit determination

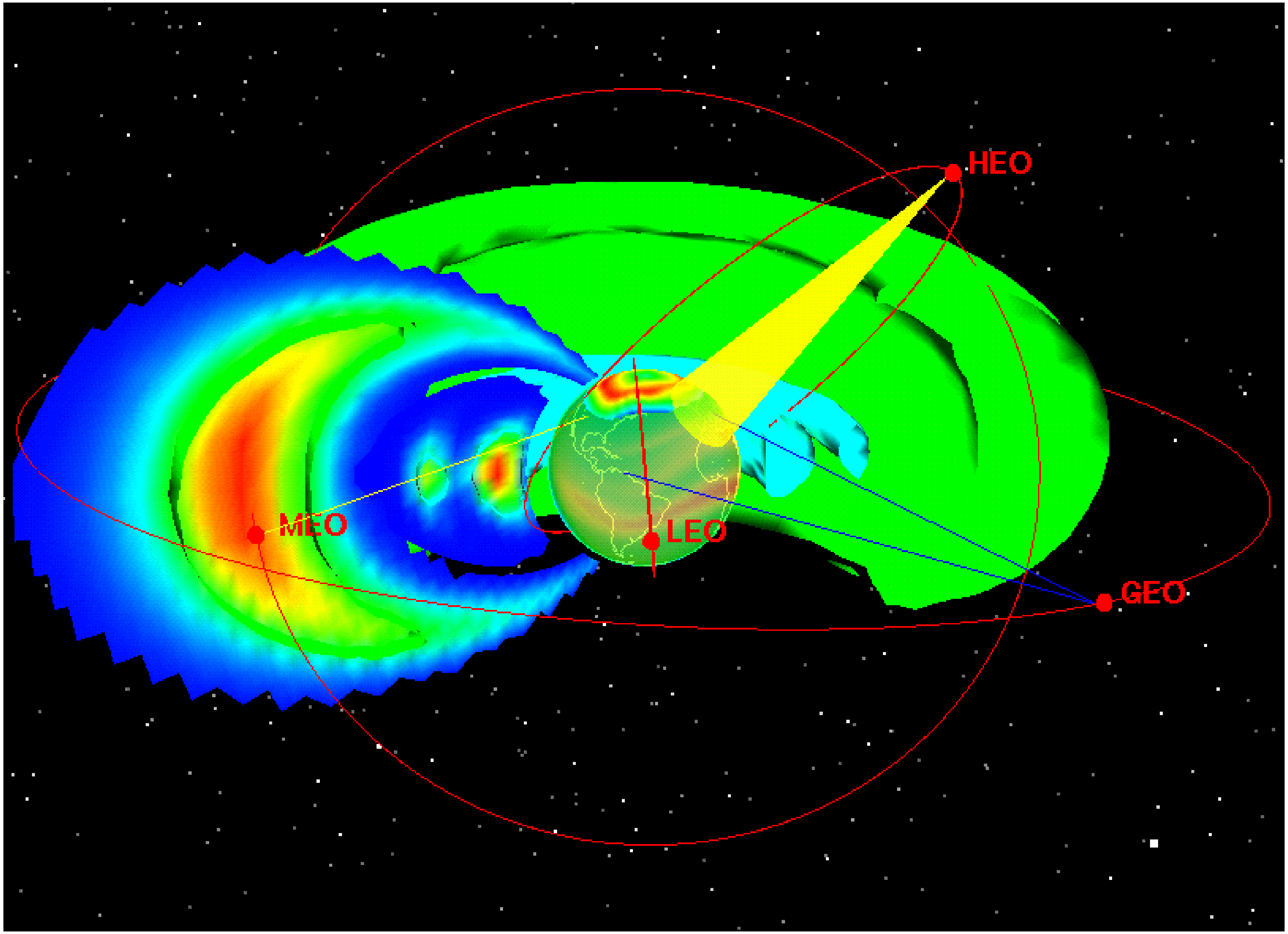
Necessary for:

- satellite position
- satellite lifetime
- satellite re-entry
- catalog of space objects
- collision avoidance
- satellite design



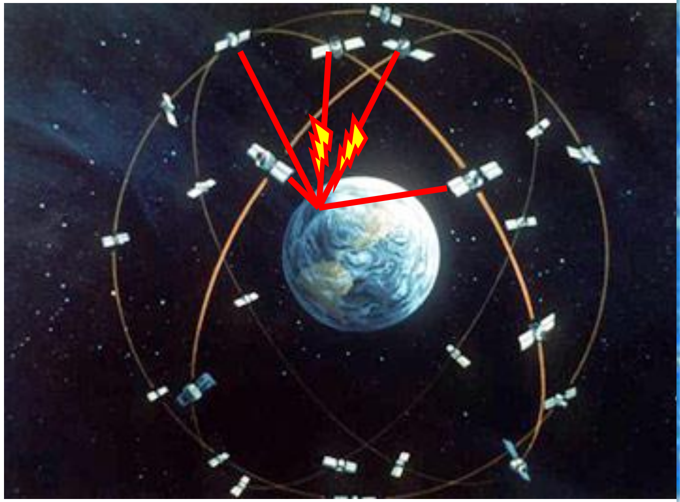
* Air Force Space Command

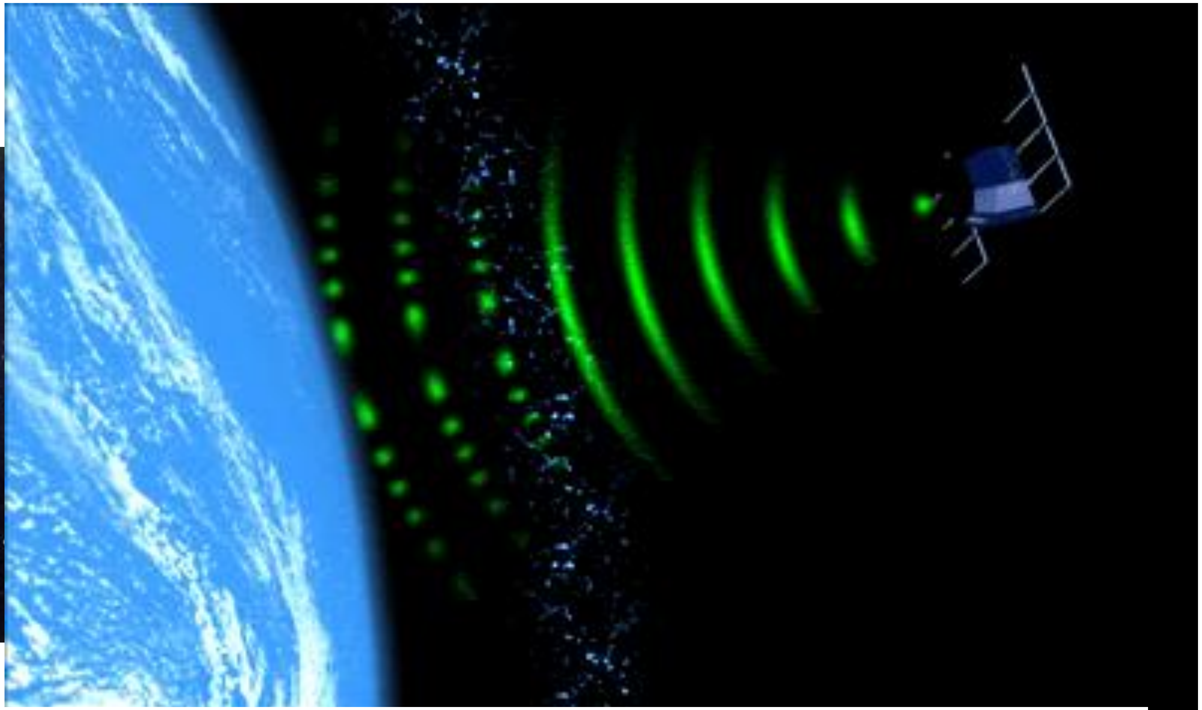
Space Weather Effects: Radiation Belt Perturbations

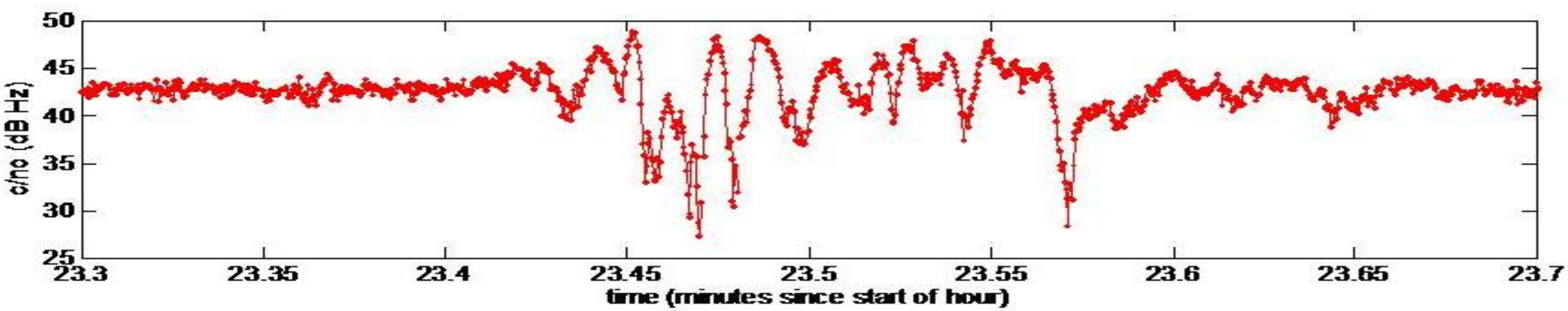


Space Weather Effects: Communications, Navigation, Surveillance

Scintillations

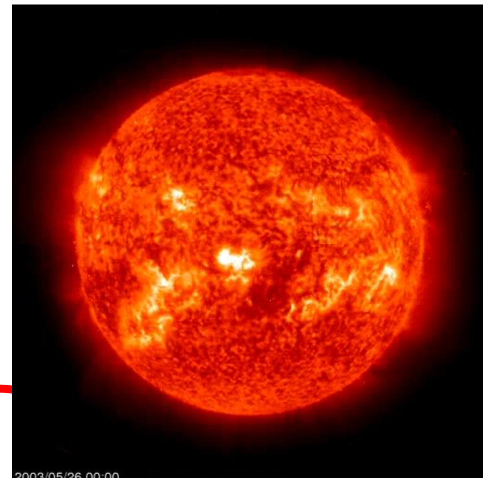




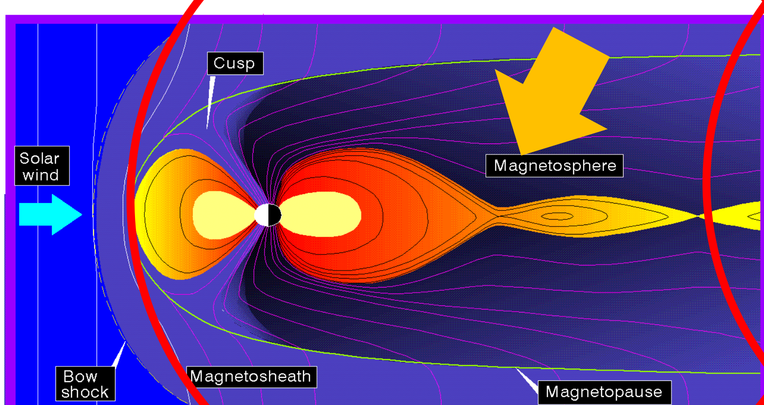


Space Sciences: Overview

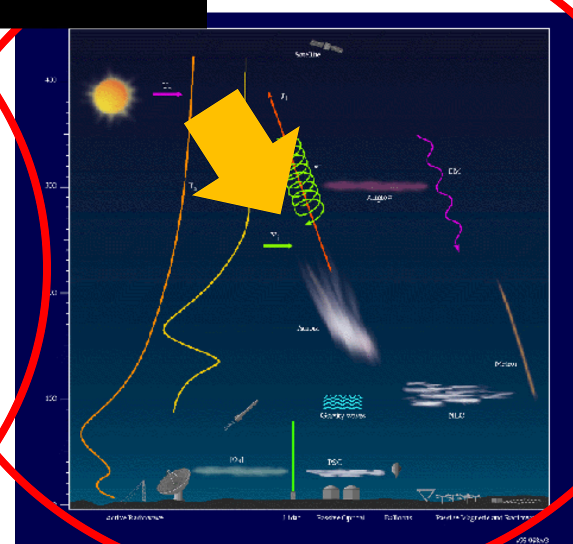
Solar Physics



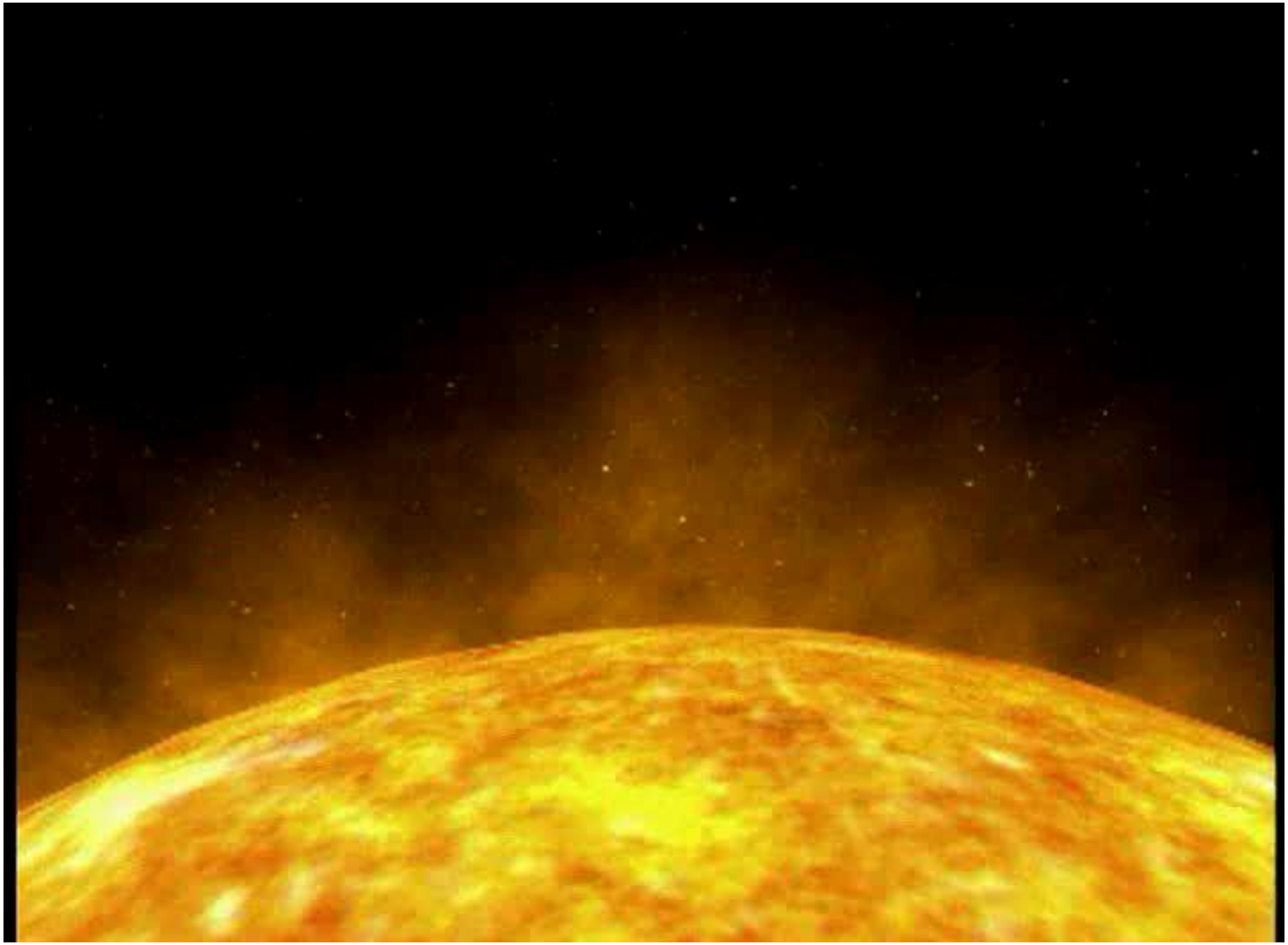
Magnetosphere/
Radiation Belts



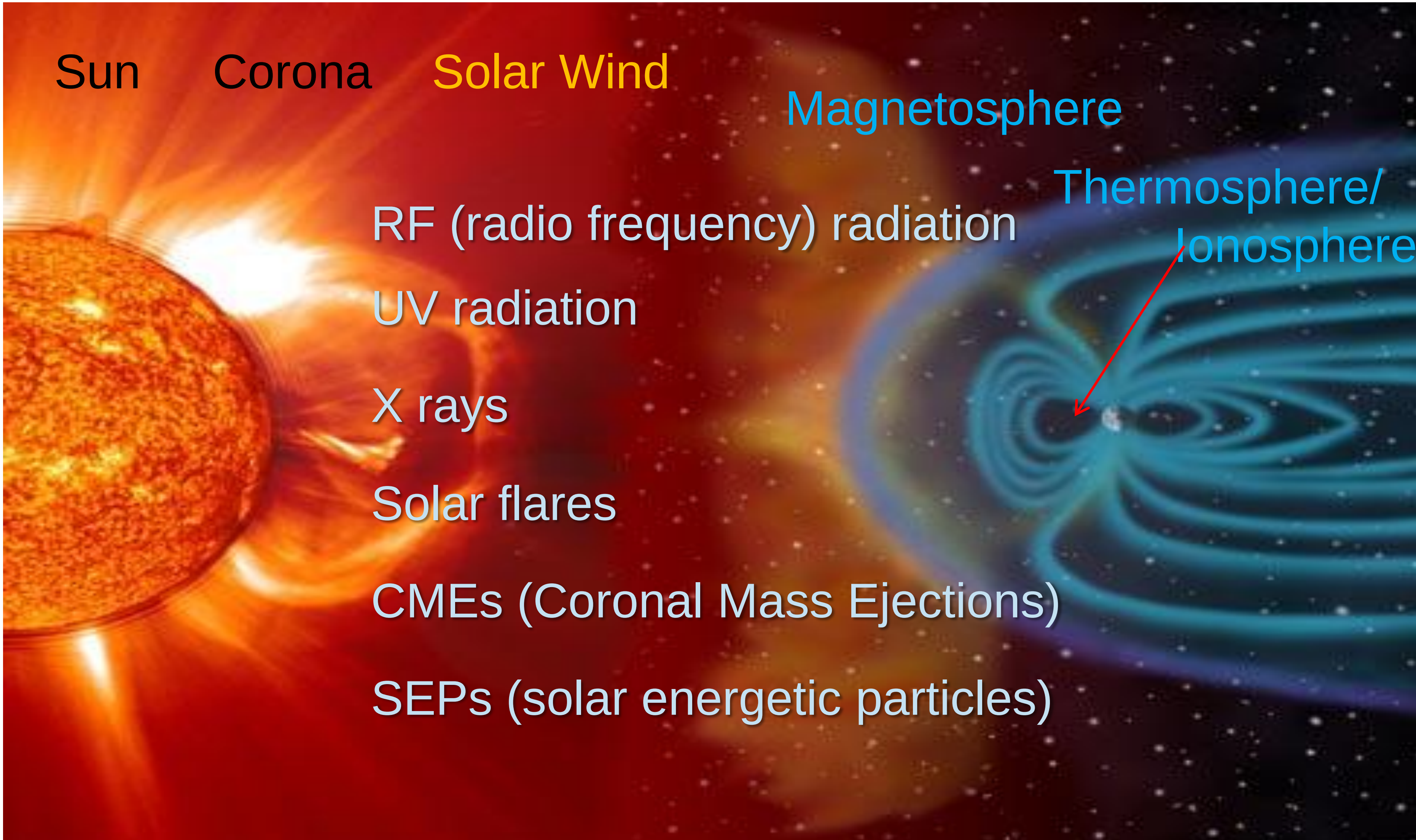
Thermosphere/
Ionosphere



Why the Sun is so important



Heliospace and Geospace Environment



Greatest Scientific Challenge

Predicting solar activity

- when it will happen
- how bad will it be
- will it hit Earth

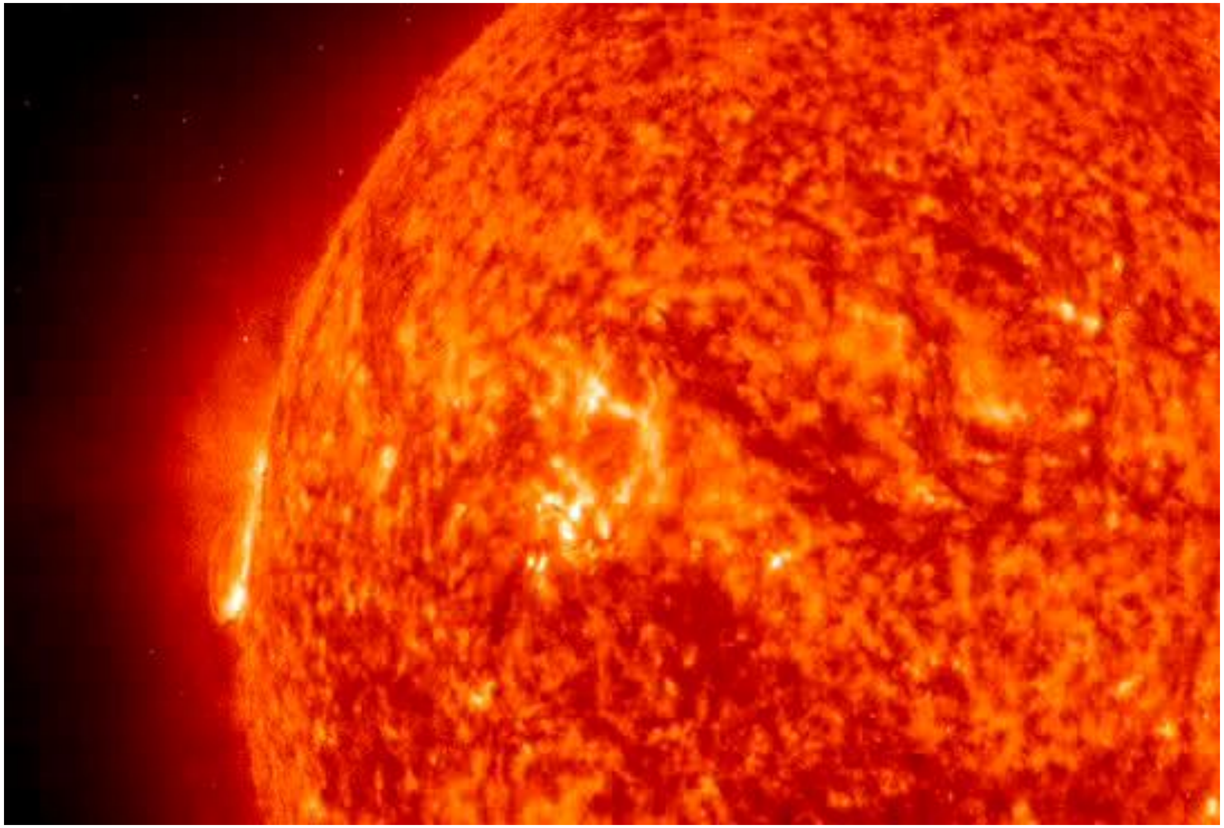
Predicting the effects on Earth

- when will it happen
- how bad will it be
- how long will it last

Transformational Opportunity

Solar Physics Research

Ultimate Goal:
Predict Flares, CMEs*, and SEPs*



NASA / Solar and Heliospheric Observatory

CME = coronal mass ejection
SEP = solar energetic particle

A Typical Space Weather Event

An Active Region Erupts

1. Solar flare (x-ray)
2. Shock
   (energetic particles)
3. Coronal Mass Ejection
   (particles and fields)

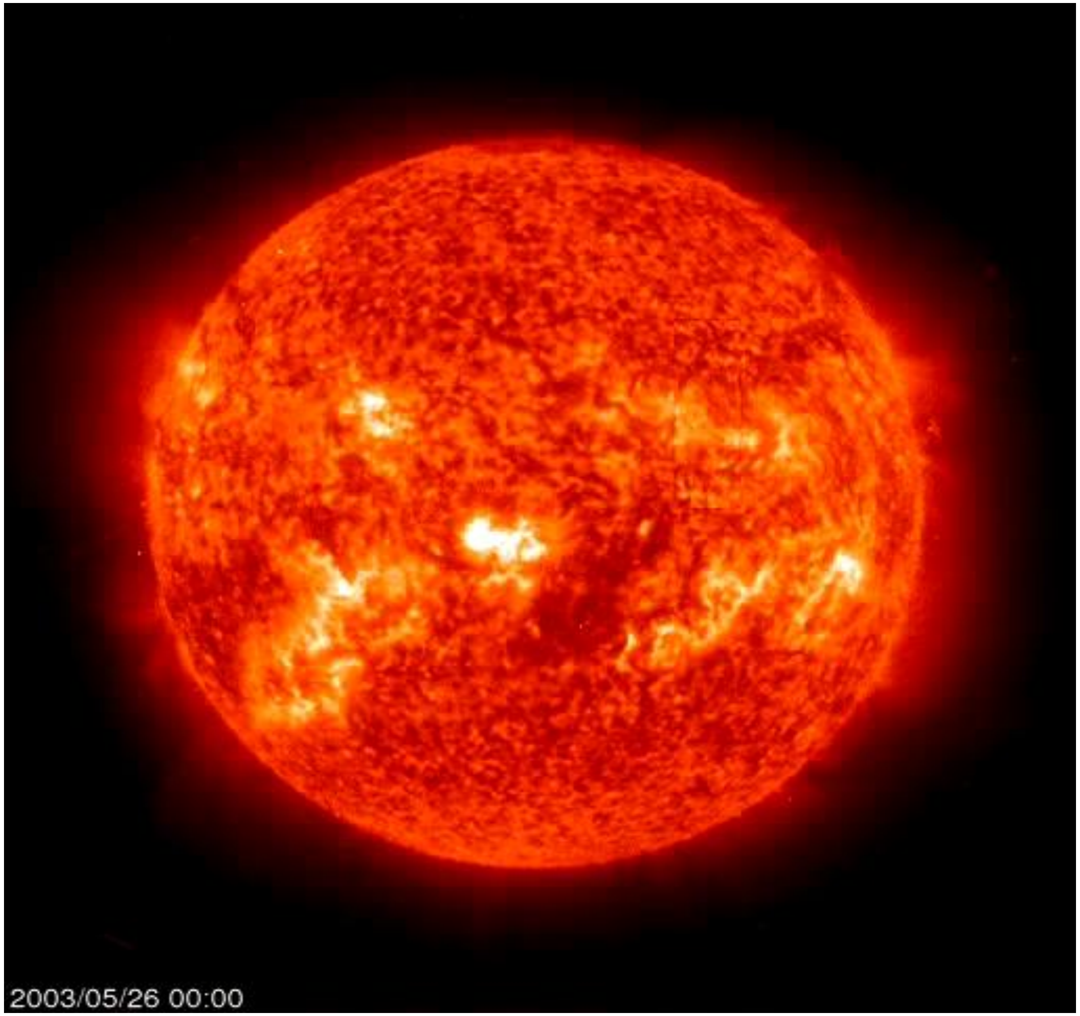
X-rays reach Earth in 8 minutes (speed of light)

Energetic particles reach Earth in 15 min to 24 hours

Coronal Mass Ejection reaches Earth in 1 – 4 days

Solar Physics Research

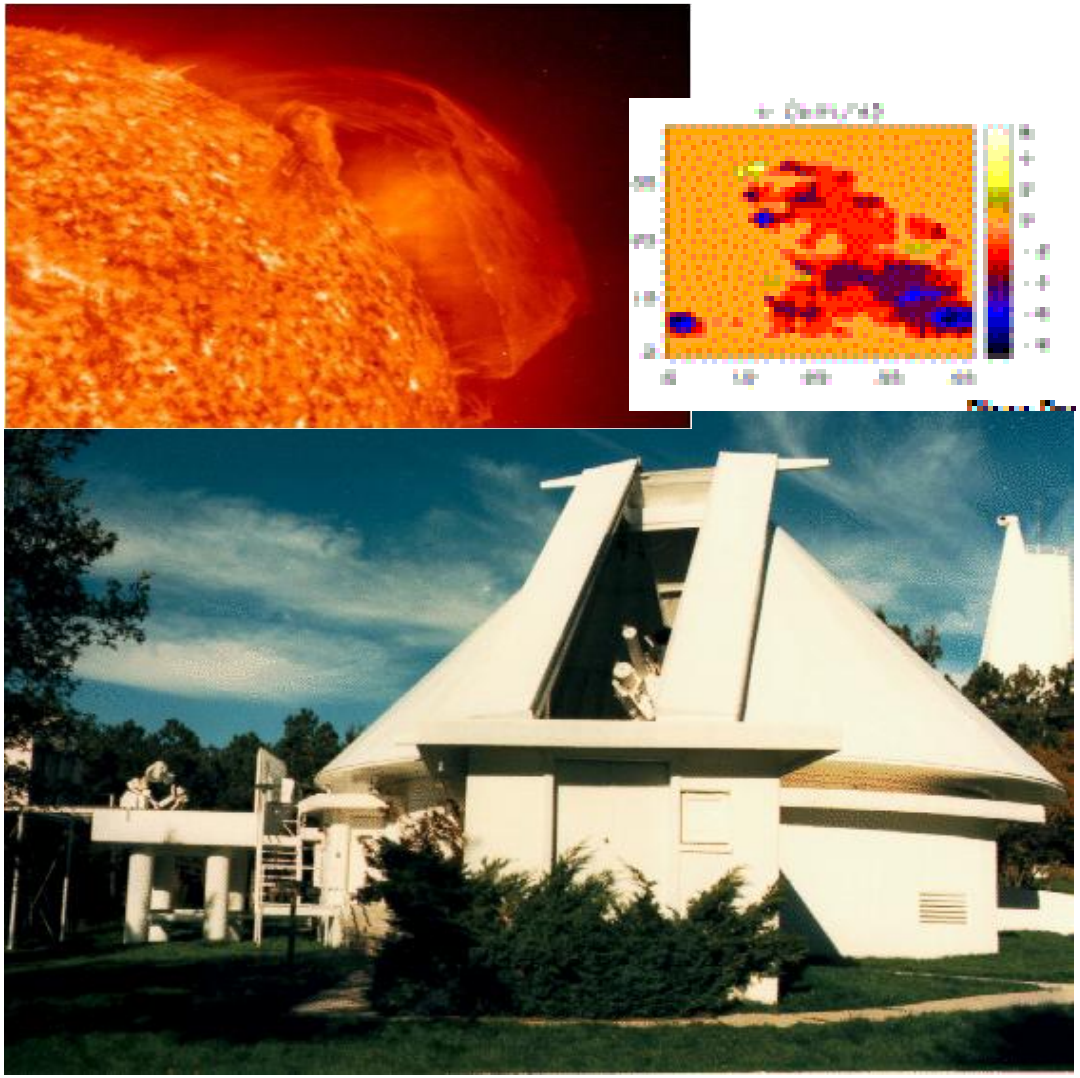
AFOSR funds a range of activities spanning observing, modeling, and laboratory work.



NASA / Solar and Heliospheric Observatory

All are ultimately geared towards achieving a predictive or forecasting capability

Solar Prominence Magnetometer



A 40-cm coronagraph at Sunspot, NM can extract information on the solar magnetic fields in the chromosphere.

The goal is to predict if and when solar prominences will erupt and result in severe disturbances to USAF assets.

PI: R. Altrock, AFRL/RV

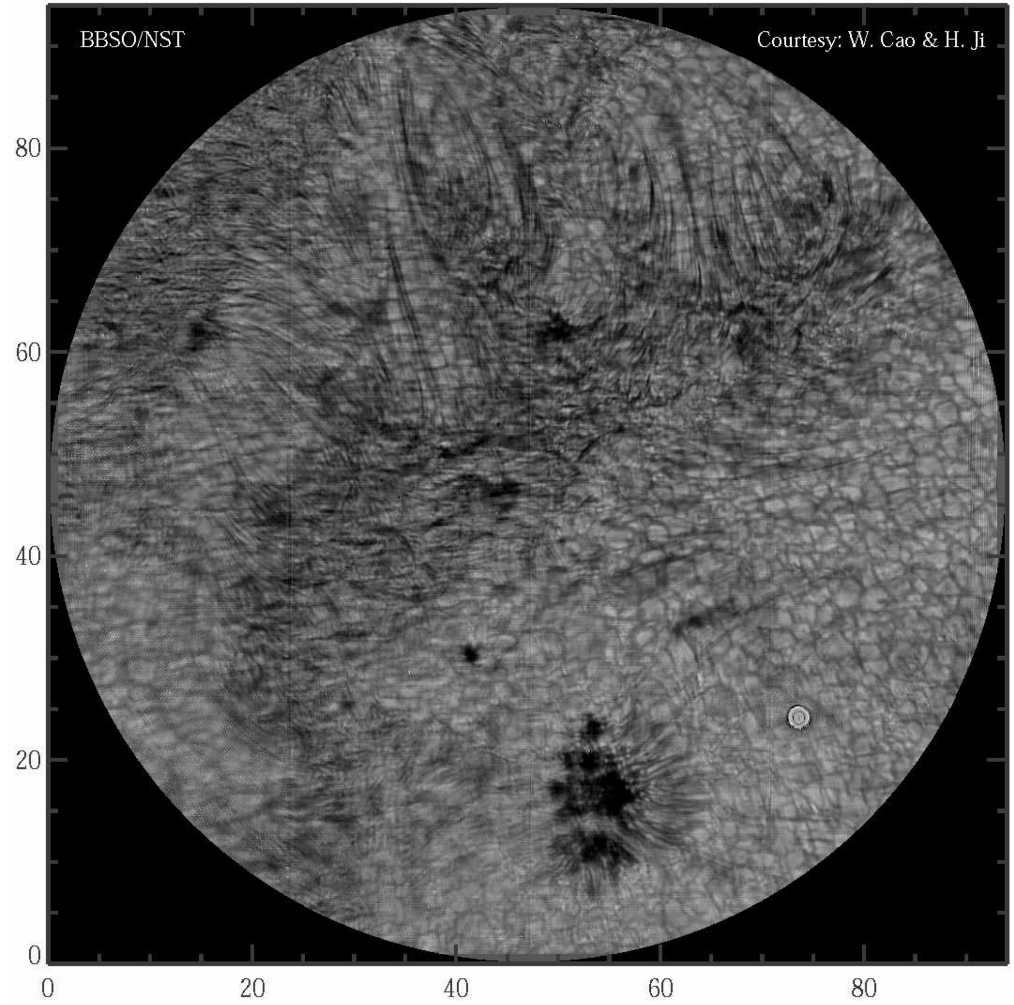
AFRL

New Solar Telescope at Big Bear, CA

The New Solar Telescope is the highest resolution ground-based solar telescope.

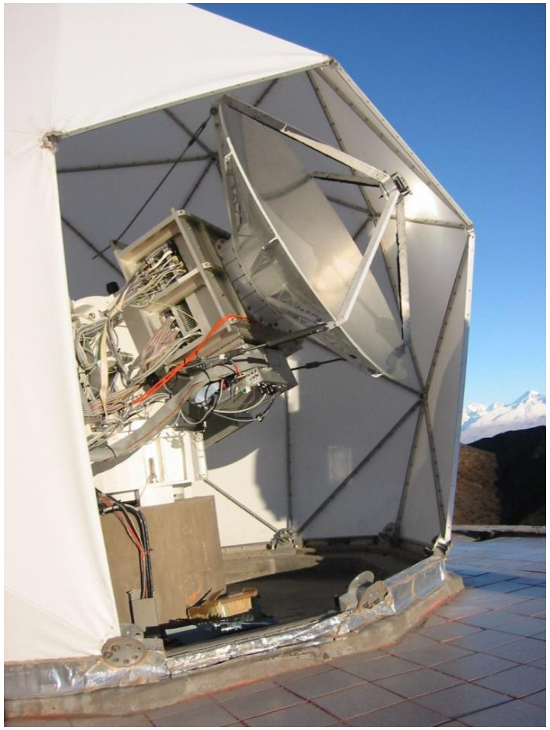
Most recent achievement: Discovery of magnetic loops reaching from the solar surface to the low corona.

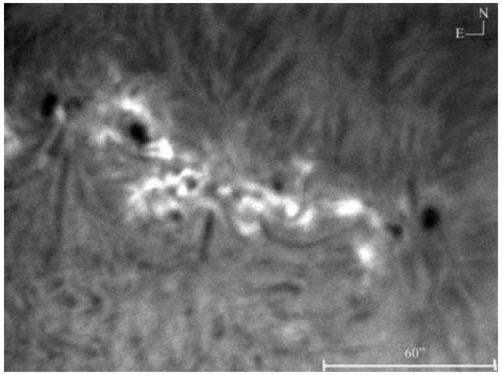
Instrument field of view is a circle 100” in diameter



PI: P. Goode, NJ Institute of Technology

Solar polarization telescopes at El Leoncito, Argentina

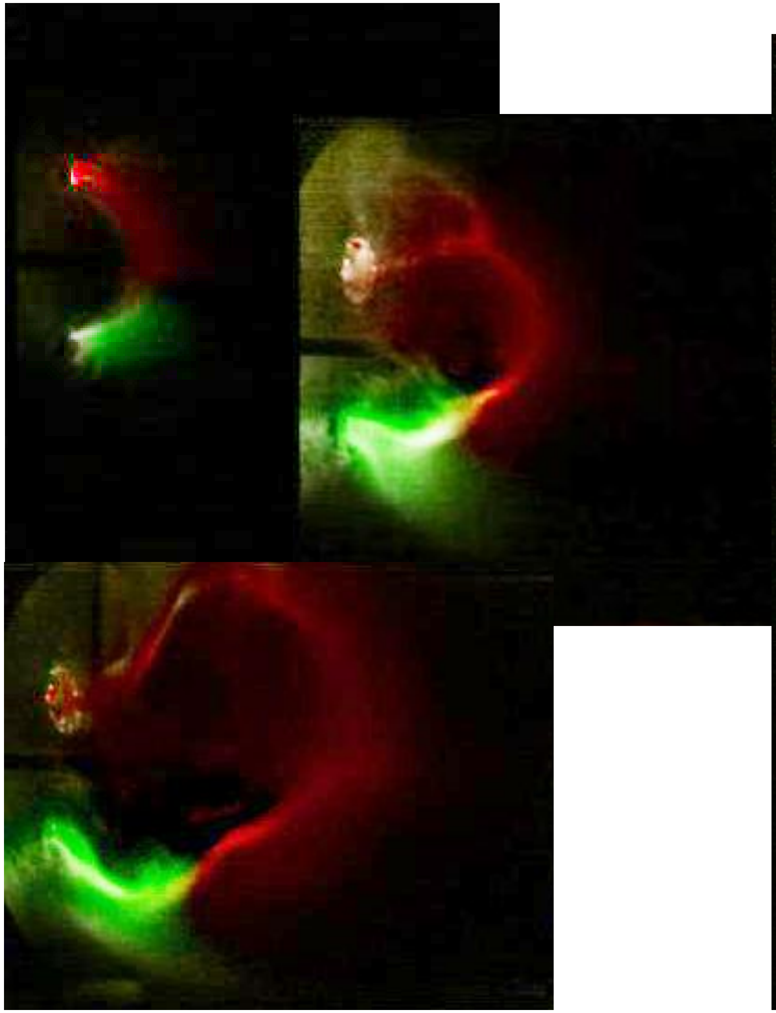




The El Leoncito Heliogeophysics Laboratory provides unique regular observations of the Sun at 45, 90, 200 and 400 GHz.

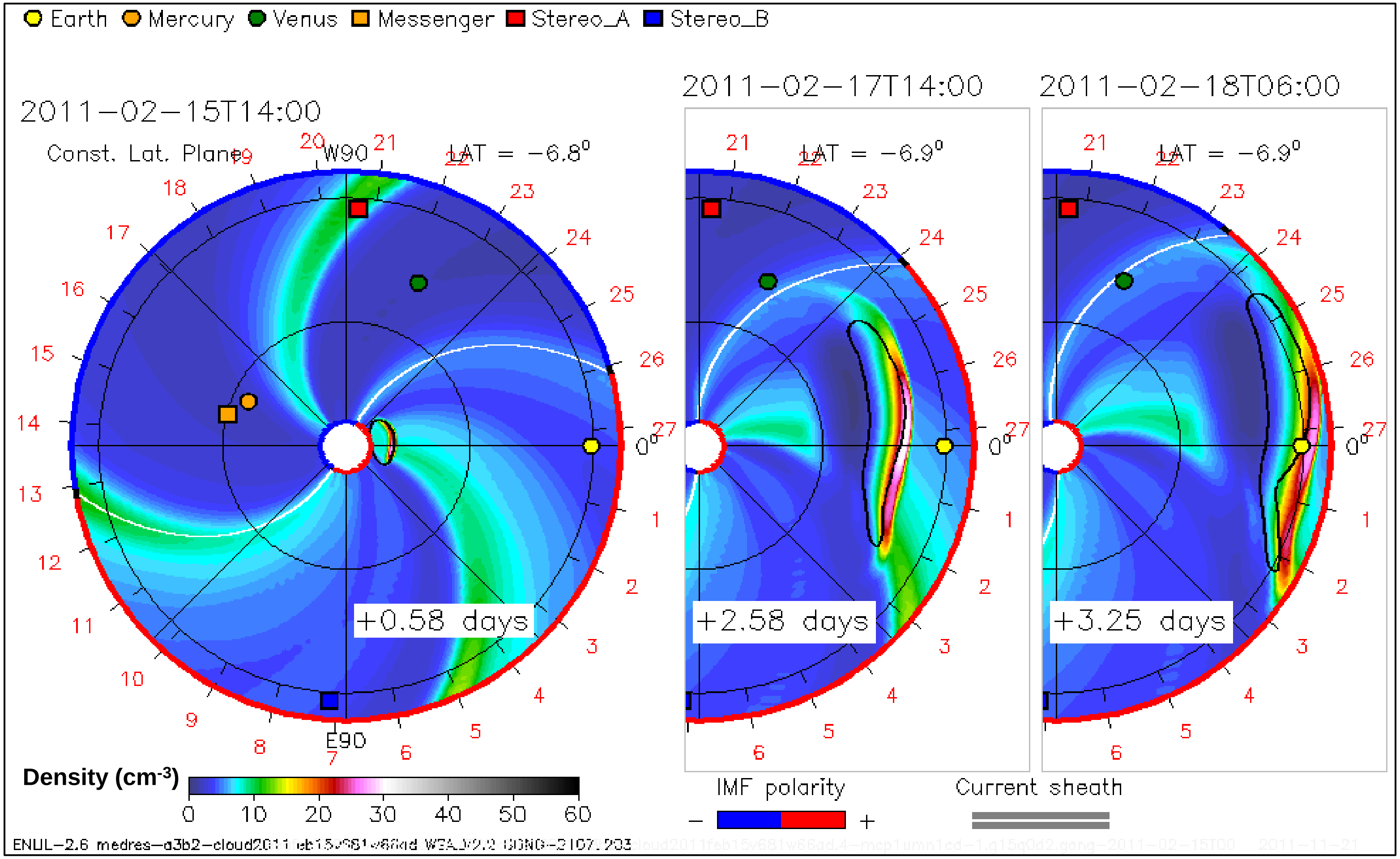
PI: P. Kaufmann, U. Presbiteriana Mackenzie, Brazil

Lab Experiments: Simulations of solar magnetic loops



PI: P. Bellan, CalTech

Simulating an Earth-directed coronal mass ejection (CME)



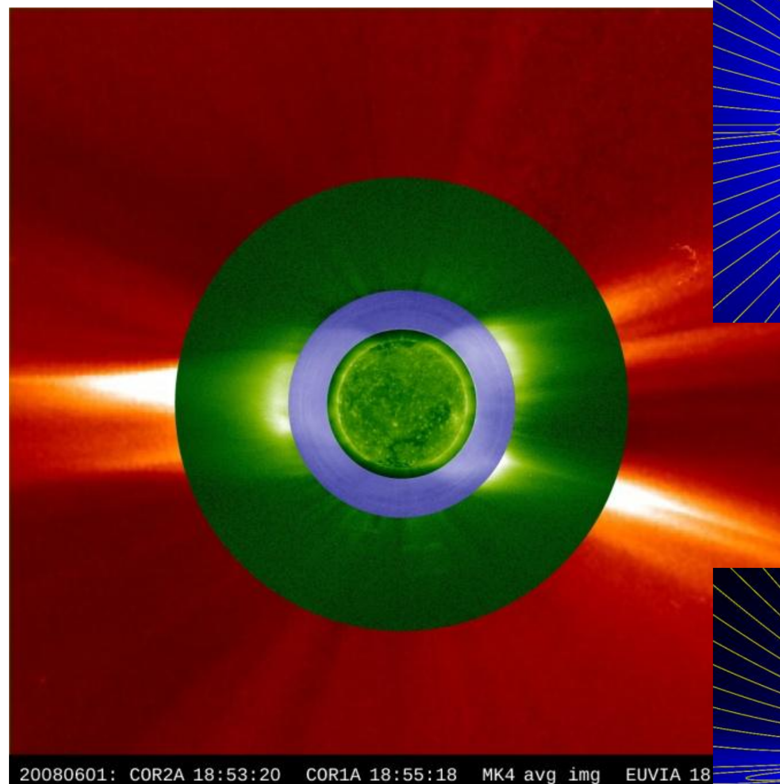
PI: C. Lee, NRC post-doc at AFRL/RV

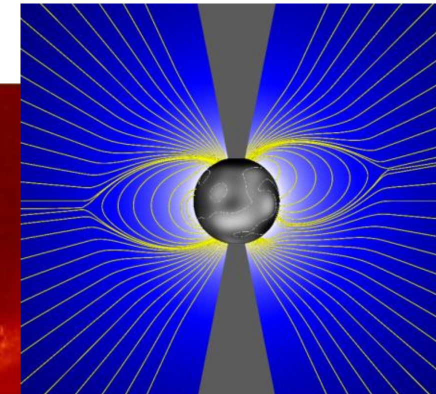
Modeling “Stealth” CMEs

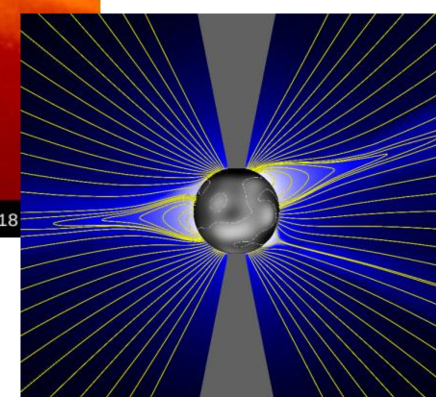
“Stealth” CMEs : CMEs with virtually no on-disk signatures (flare, EUV dimming, prominence eruption

How do you predict a CME and its geoeffectiveness if you didn’t see it erupt or cannot identify the source region?

To address this, the project is running MHD simulations of the 2008 Jun 2 “stealth” CME in a simplified background solar wind





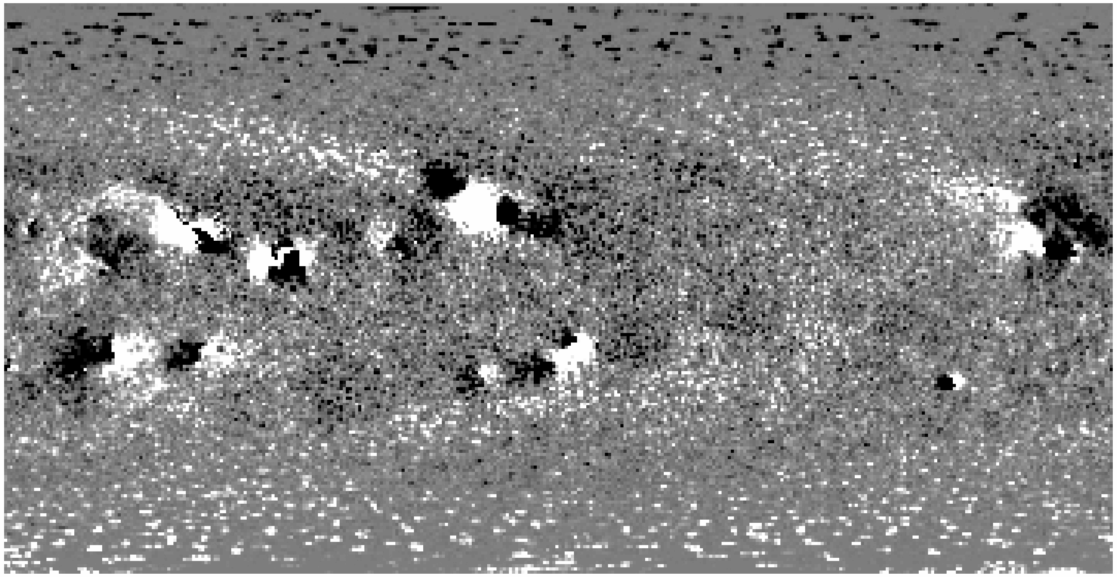


YIP PI: B. Lynch, UC-Berkeley

First physics-based space weather model to transition to operations

ADAPT model*: Air Force Data Assimilative Photospheric Flux Transport (ADAPT) Model

ADAPT provides high quality “snapshots” of the Sun’s global magnetic field; this is the primary input for *all* coronal and solar wind models.



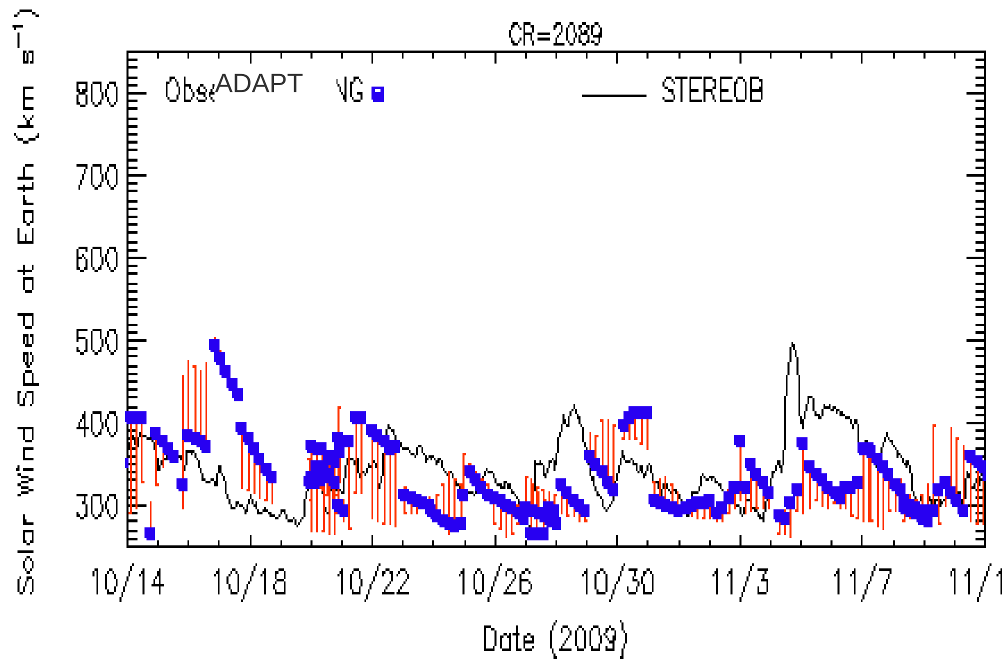
PI: C.N. Arge, AFRL/RV

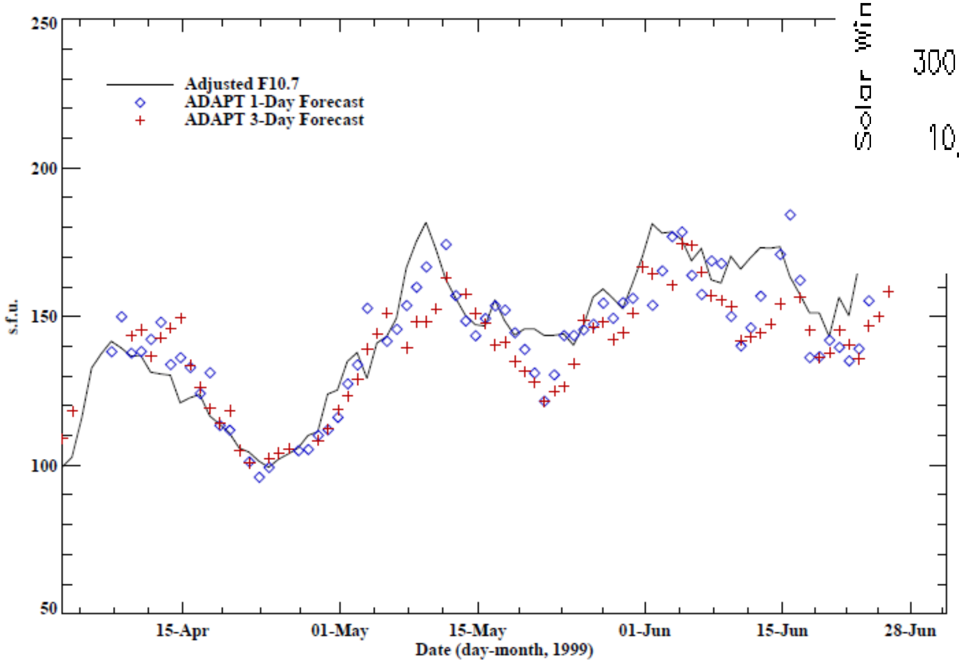
***RV’s newest Star Team**

Additional ADAPT activities

Using ADAPT Maps

Solar Wind Predictions vs. Observations at STEREO B



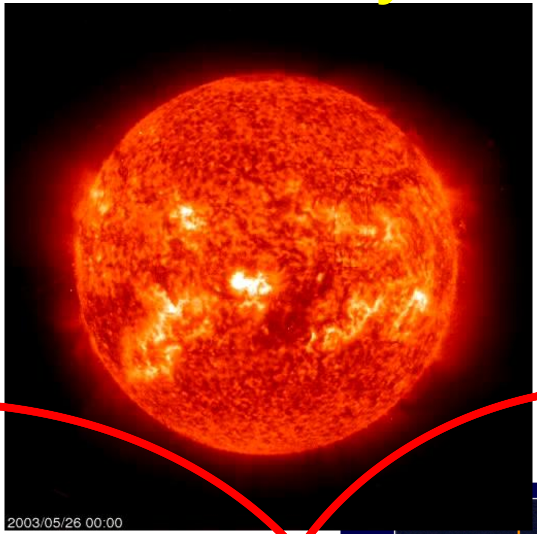


Development of a new method to forecast the solar 10.7 cm radio flux

PI: C.N. Arge, AFRL/RV

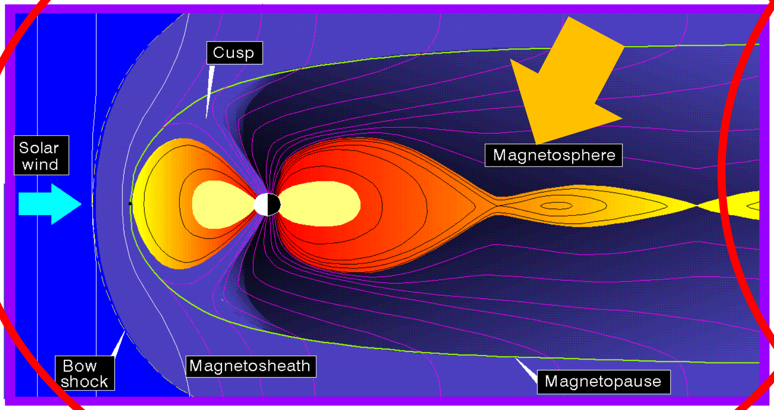
Space Sciences: Overview

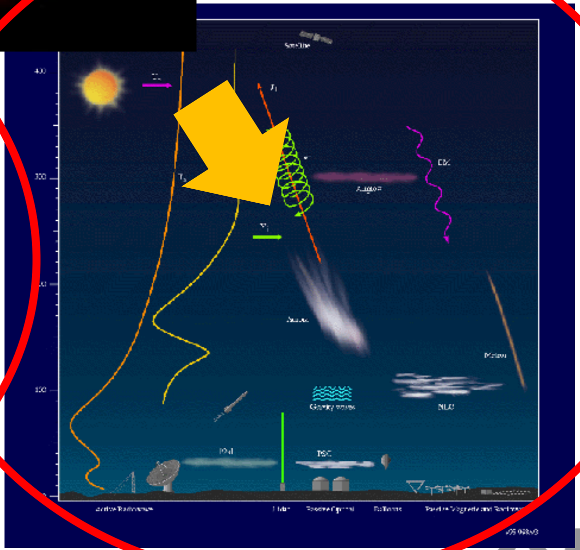
Solar Physics



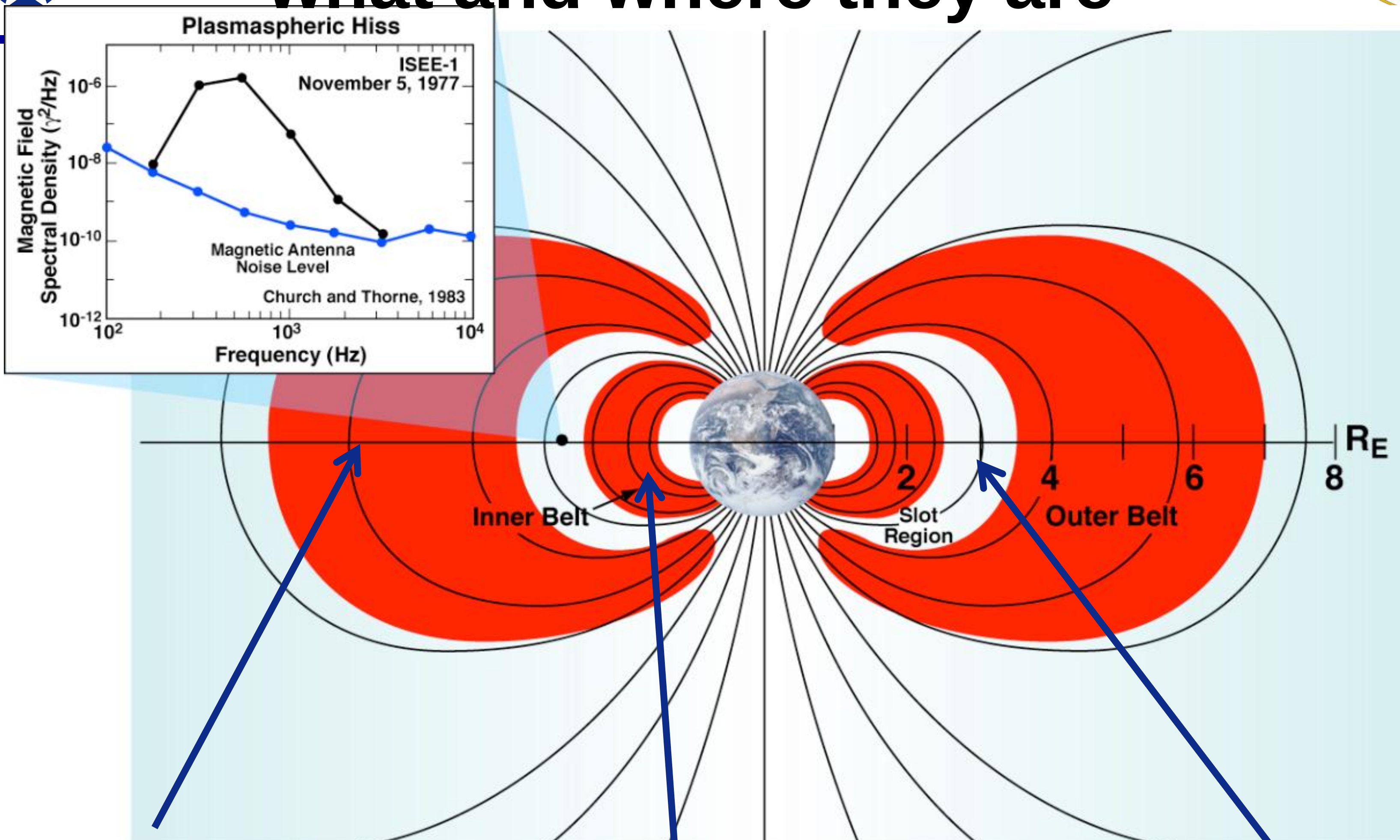
Magnetosphere/
Radiation Belts

Thermosphere/
Ionosphere





Earth’s Radiation Belts: what and where they are



Energetic **electrons** (0.1 – 10 MeV)

Energetic **protons** (10-50 MeV) + Electrons (0.04 – 4.5 MeV)

Slot region

Earth's Radiation Belts: Why they are important

They pose hazards for

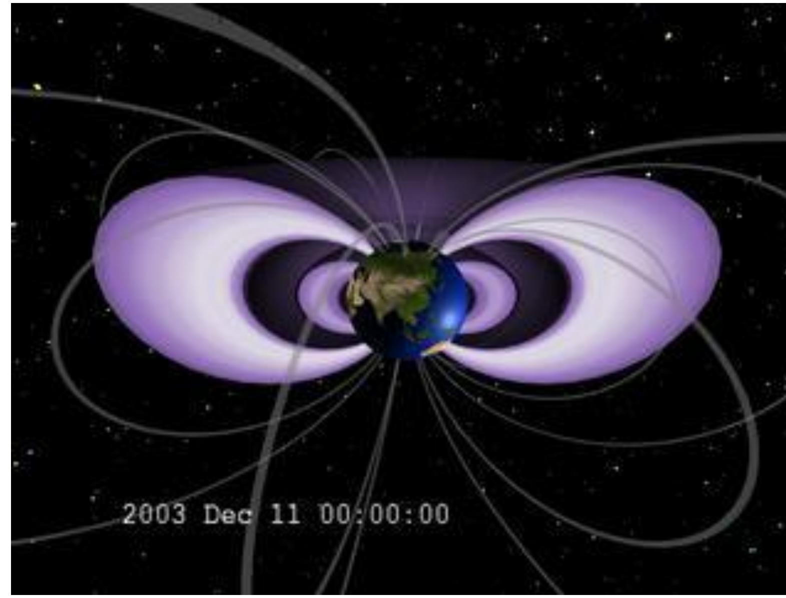
- Astronauts
- Spacecraft
- Hardware

compromising

- Mission performance
- Mission lifetimes

since they can lead to

- Material degradation
- Single Event Upsets (SEUs)
- Internal charging
- Surface charging



Magnetospheric Physics at AFOSR

AFOSR's magnetospheric physics investments are focused on a few key areas of particular interest to the AF.

The projects include state-of-the-art modeling of the energetic particles in the radiation belts including diffusion and accounting for wave-particle interactions.

Modeling and Theory Investigations

Modeling radiation belt electrons with quasi-linear **diffusion** driven by resonant waves

PI: J. Albert, AFRL/RV

pitch angle diffusion

cross diffusion

$$\frac{\partial f}{\partial t} = \frac{1}{G}\frac{\partial}{\partial\alpha_0} G\left(\frac{D_{\alpha_0\alpha_0}}{p^2}\frac{\partial f}{\partial \alpha_0} + \frac{D_{\alpha_0 p}}{p}\frac{\partial f}{\partial p}\right) + \frac{1}{G}\frac{\partial}{\partial p}G\left(\frac{D_{\alpha_0 p}}{p}\frac{\partial f}{\partial\alpha_0} + D_{pp}\frac{\partial f}{\partial p}\right) + L^2\frac{\partial}{\partial L}\frac{D_{LL}}{L^2}\frac{\partial f}{\partial L}$$

cross diffusion

energy diffusion

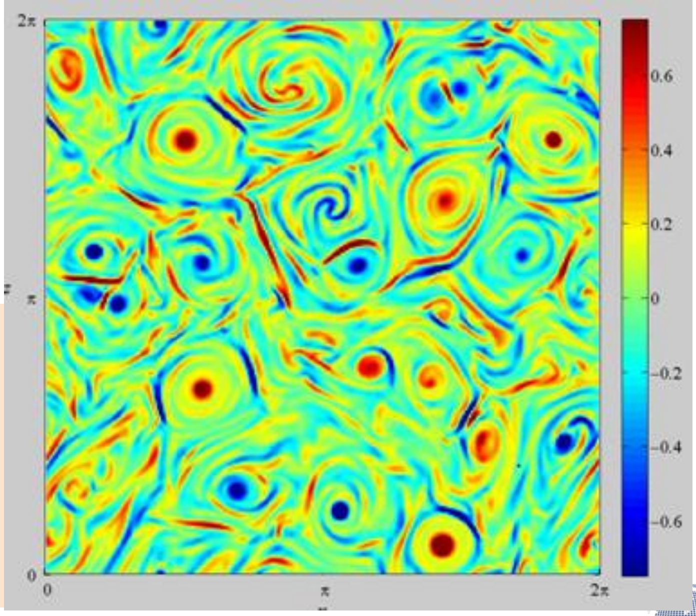
radial diffusion

Developing a computationally efficient new multi-fluid hybrid model for collisionless plasma

YIP PI: R. Burrows, U. Alabama

Developing a new theory of invariant curves for the analysis of intermittent turbulence

PI: T. Chang, MIT

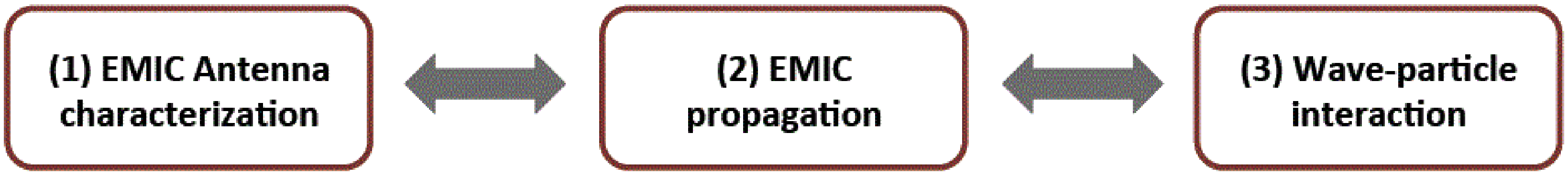


Hot Topic: Radiation Belt Remediation (RBR)

RBR: remove/drain high energy particles from the belts

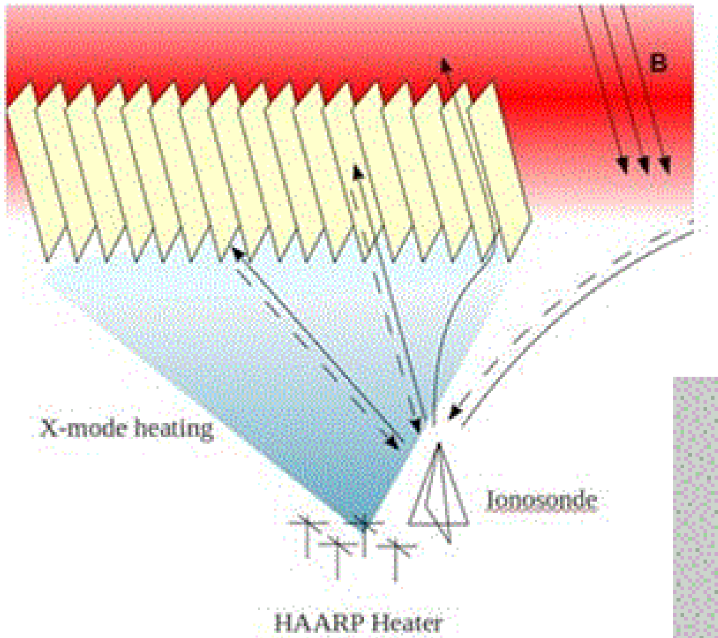
One popular idea: use spaceborne antenna to inject SLF/VLF waves into the belts. These waves scatter high energy particles down into the atmosphere.

One project: determine the characteristics and effects of a space-borne antenna radiating Electomagnetic Ion Cyclotron Waves.



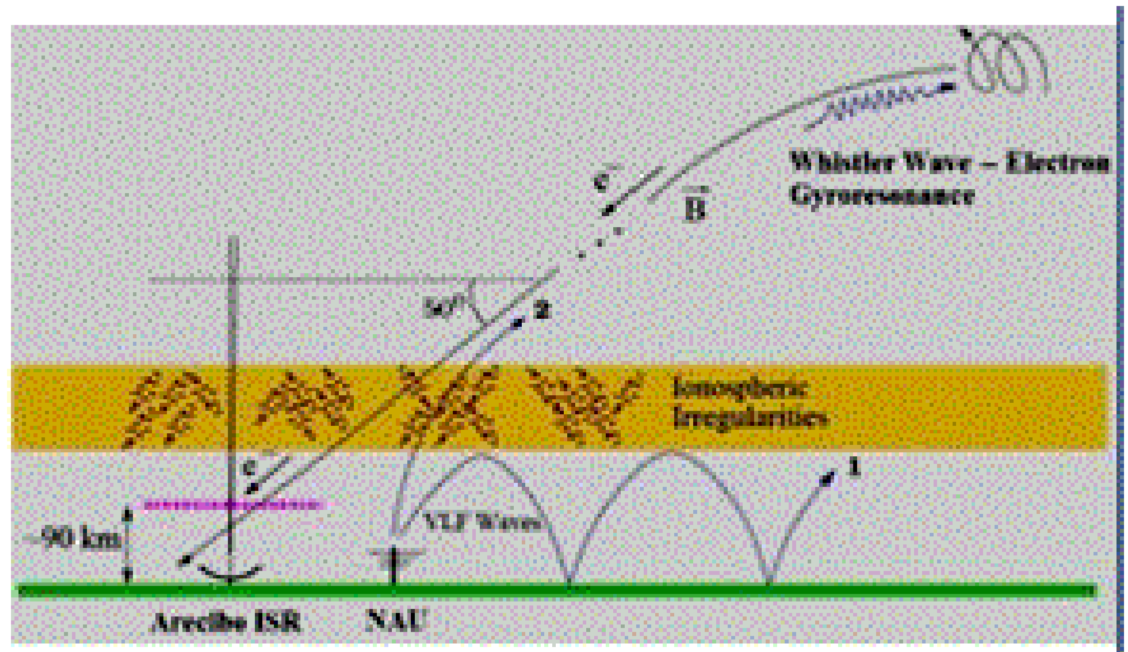
PI: M. Martinez-Sanchez, MIT

An active experiment: Generating VLF Whistler Waves



Whistler waves interact with ionospheric plasma and radiation belts sequentially

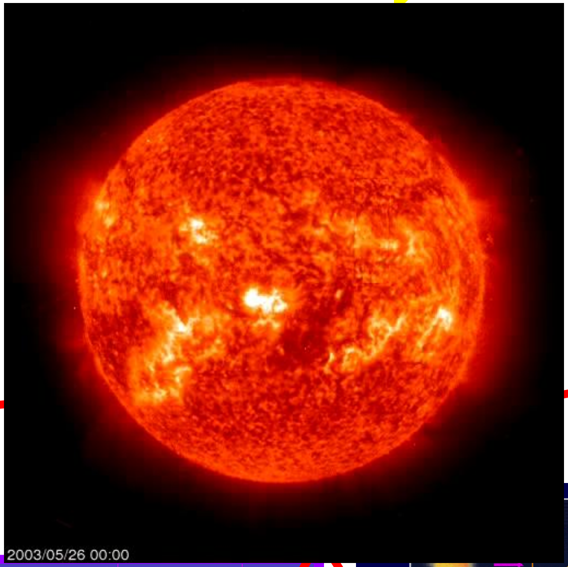
Experiments at Gakona, Alaska, to generate beat waves of VLF whistlers by HF heater waves



PI: M. C. Lee, MIT

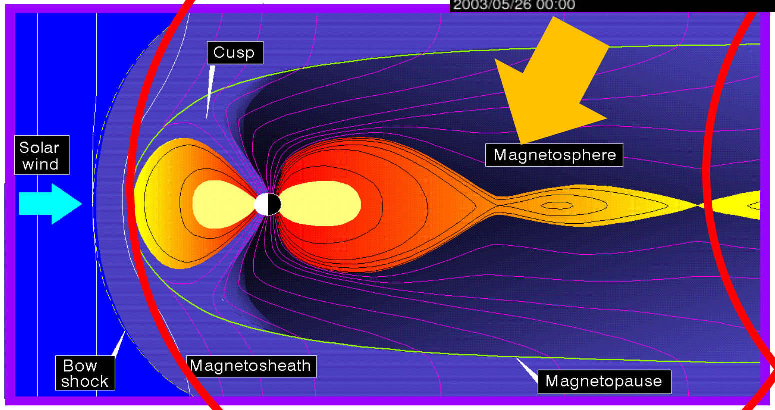
Space Sciences: Overview

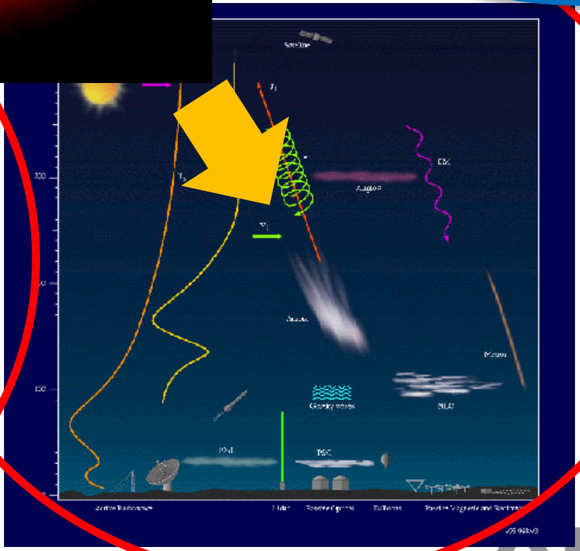
Solar Physics



Magnetosphere/
Radiation Belts

Thermosphere/
Ionosphere





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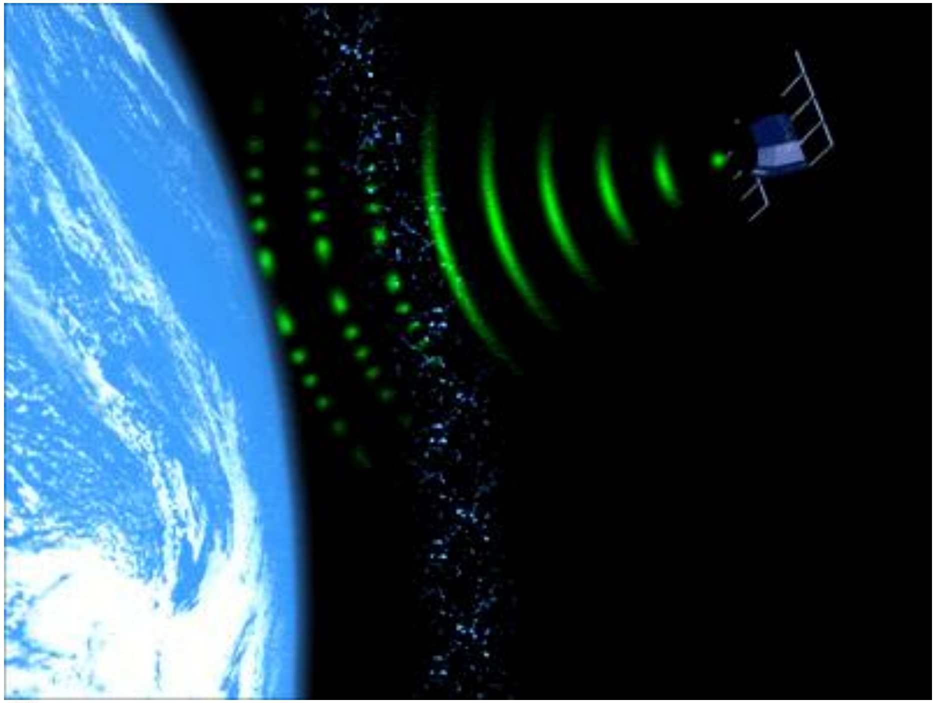
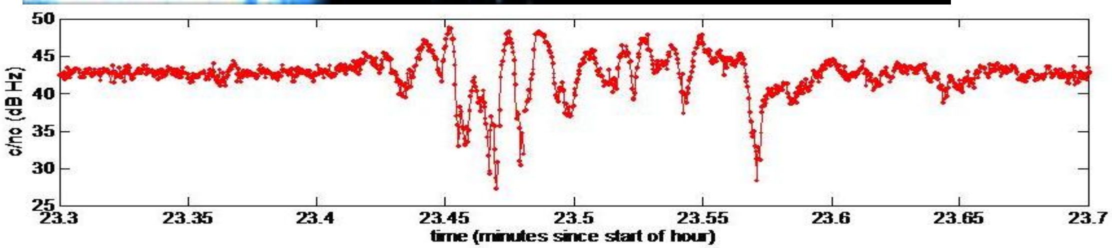
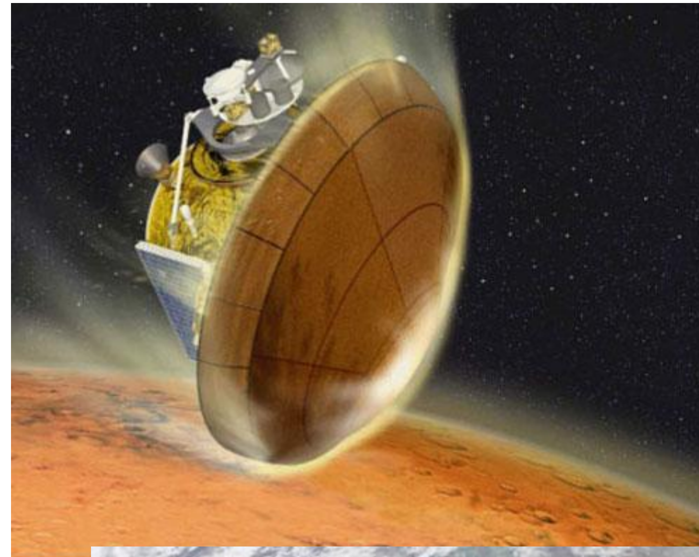
Major Issues: Scintillations and Satellite Drag







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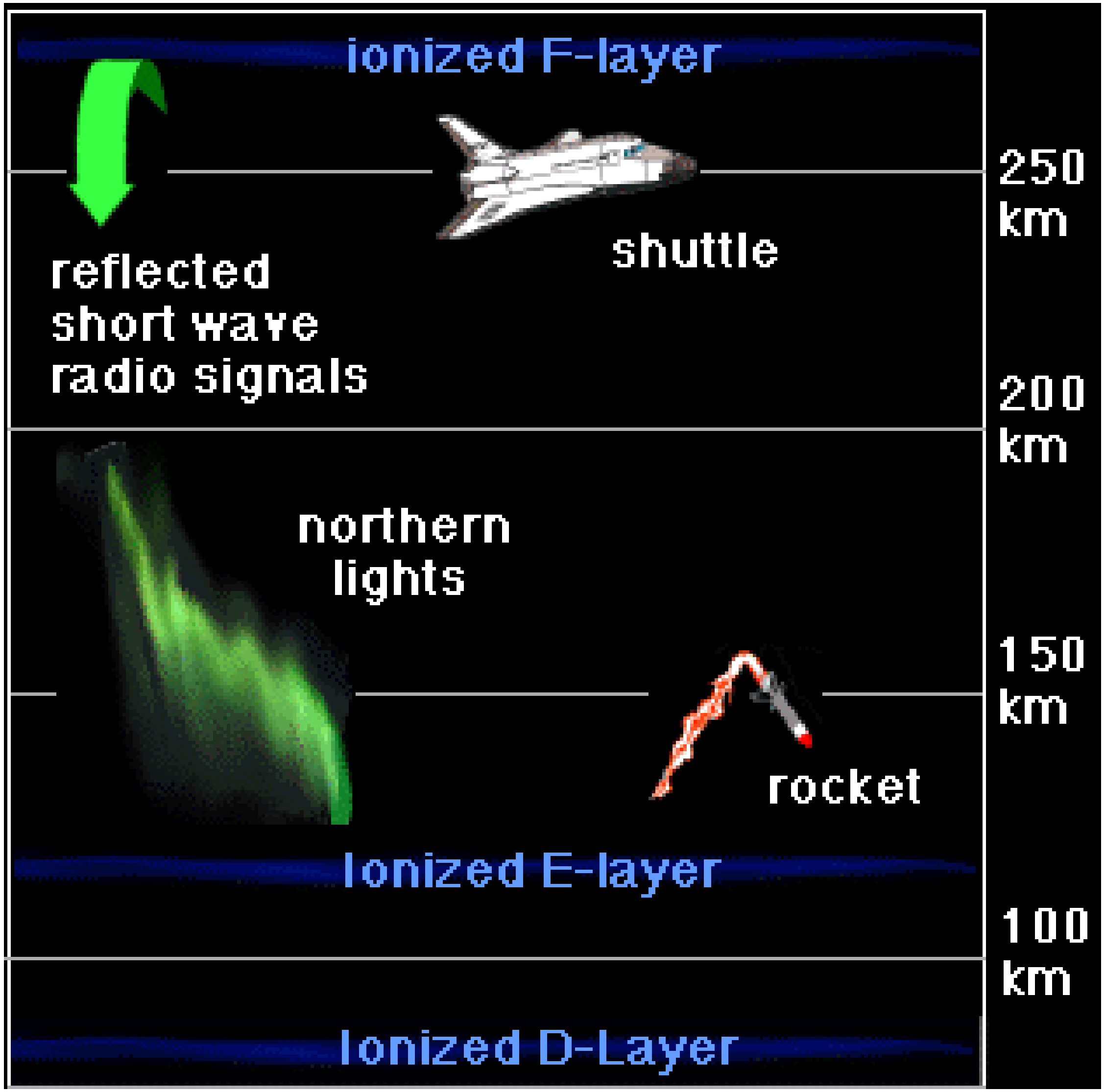
The Upper Atmosphere and Ionosphere

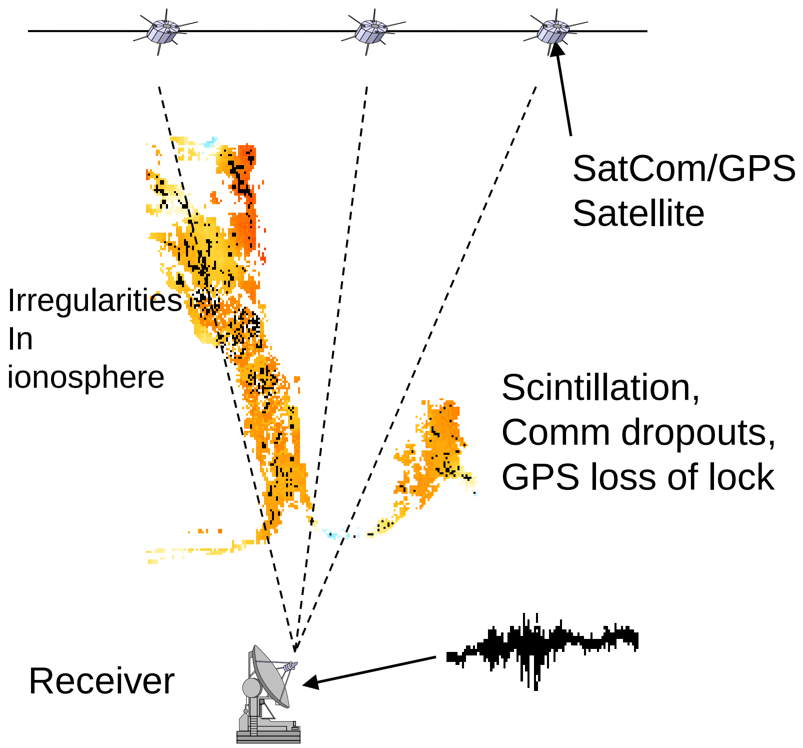


Above about 100 km, the neutral part of the atmosphere is called the **thermosphere**

Above about 80 km, the charged/ionized part of the atmosphere is called the **ionosphere**

Ionosphere Effects: Scintillations

Scintillations are caused by irregularities or perturbations in the ionosphere on various scales from very small to very large.



Being able to predict scintillations would be hugely beneficial to the DoD and to society in general.

This requires:

- characterizing the background ionosphere
- identifying the sources of scintillations
- being able to simulate the ionosphere, the sources, and the development and evolution of the irregularities

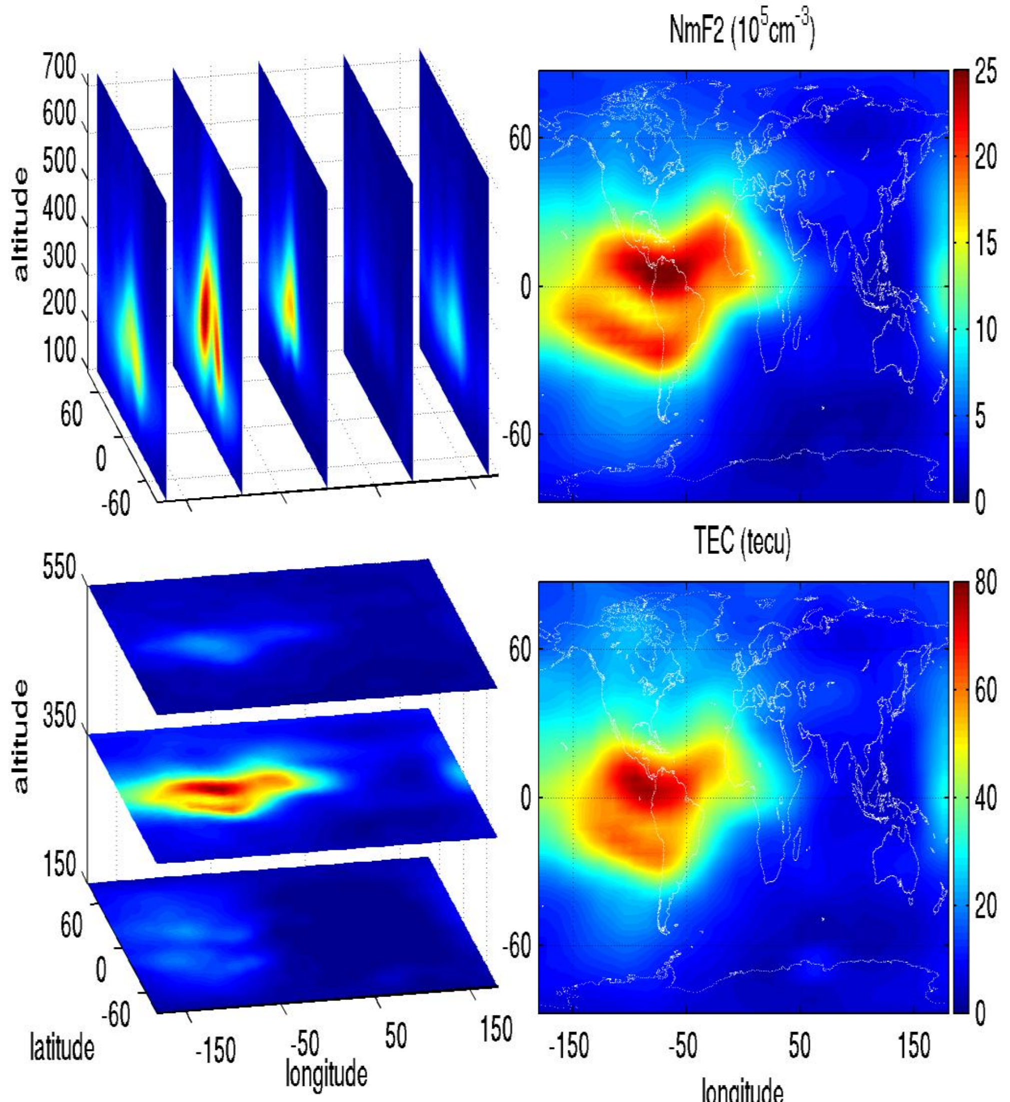
Global 3D Electron Densities

Advances in characterizing the background ionosphere using global data assimilation of the growing number of databases:

1) slant TEC from global ground-based GNSS

2) nadir vertical TEC from Jason-1/2

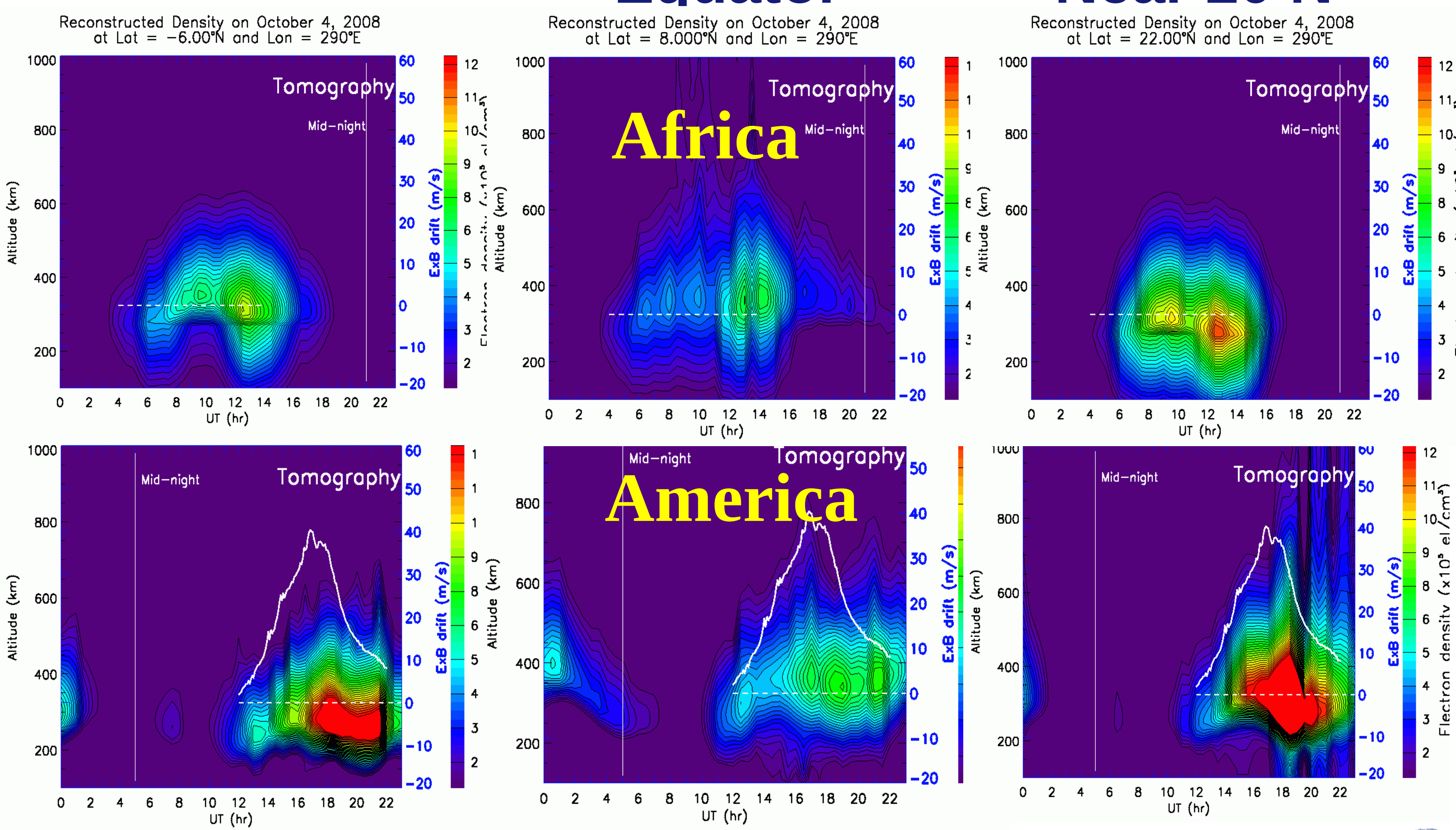
3) slant TEC from Multi radio occultation missions (COSMIC, CHAMP, GRACE, SAC-C, TerraSAR-X, and Metop-A)



PI: W. Schreiner, UCAR

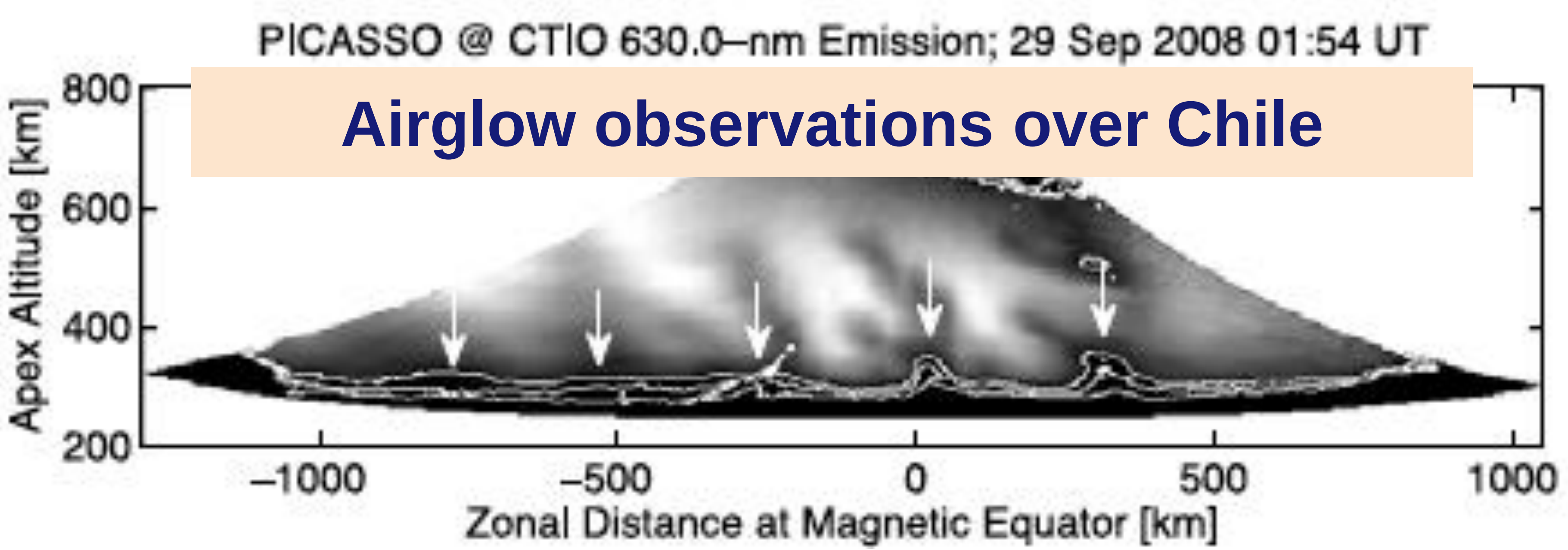
Longitude Differences

Near 20 S | Equator | Near 20 N



PI: E Yizengaw, Boston College

Evidence for lower atmosphere effects (1)



Airglow observations over Chile

Analysis of this periodicity over 3 years shows a distribution similar to that expected for gravity waves propagating into the lower thermosphere, suggesting that these waves may be a viable seeding mechanism for instabilities.

PI: J. Makela, U Illinois

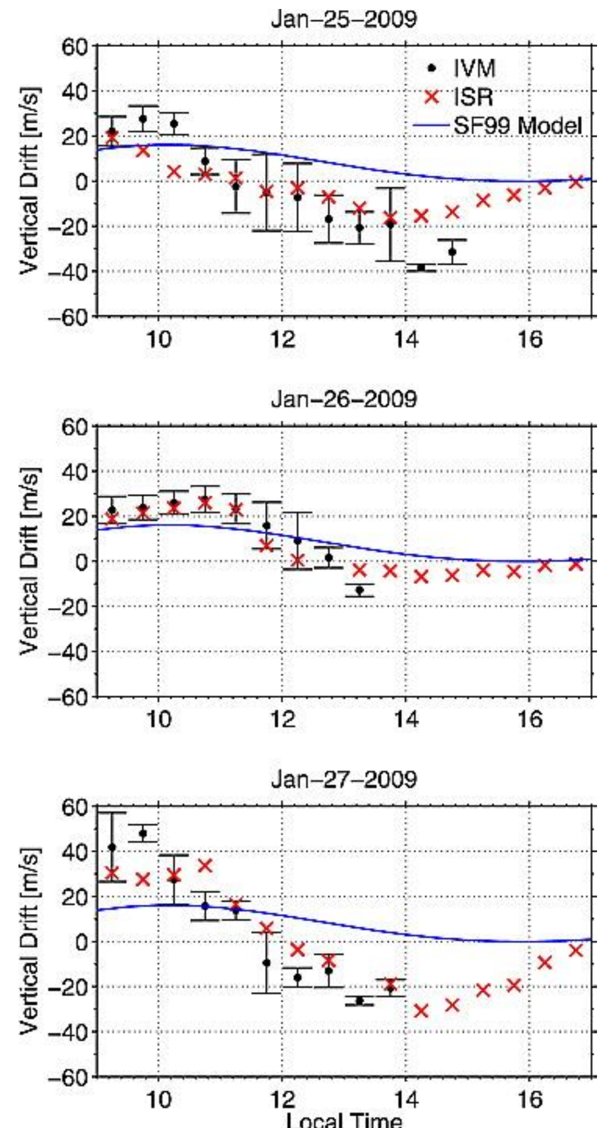
Evidence for lower atmosphere effects (2)

C/NOFS satellite observations during the 2009 major sudden stratospheric warming event (SSW)

Measurements made near Peru show two remarkable features:

- large ion velocities in the morning
- large downward velocities in the afternoon

→ SSWs can severely disturb the ionosphere

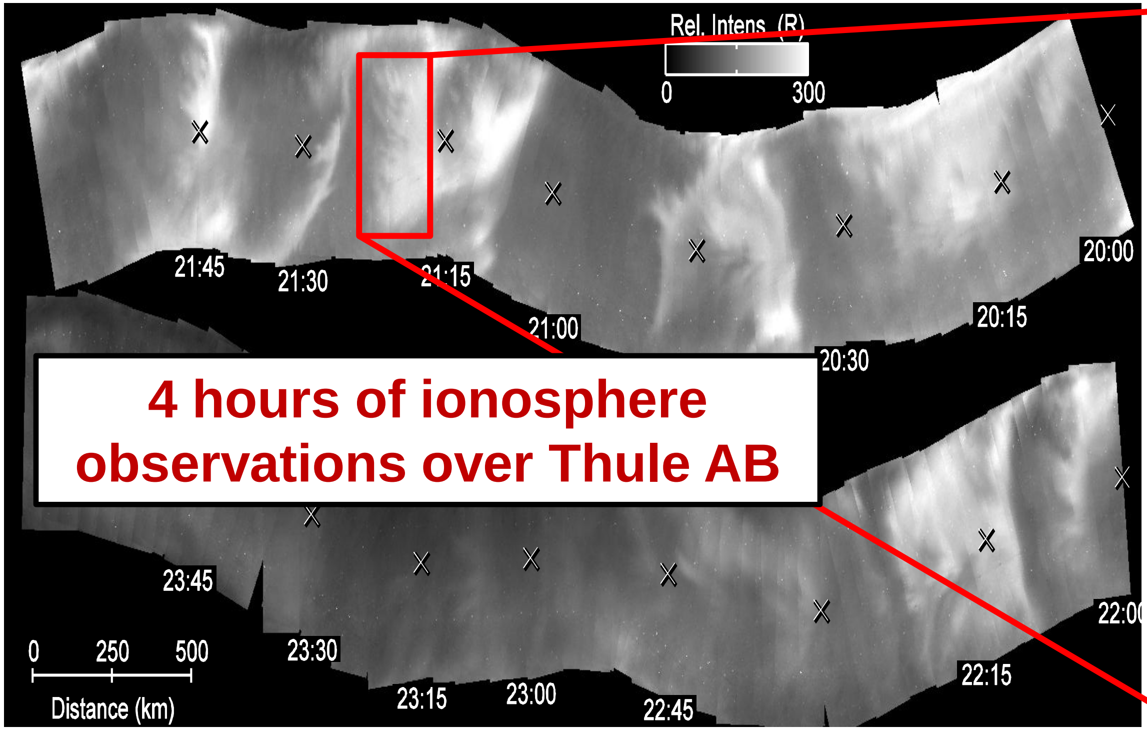


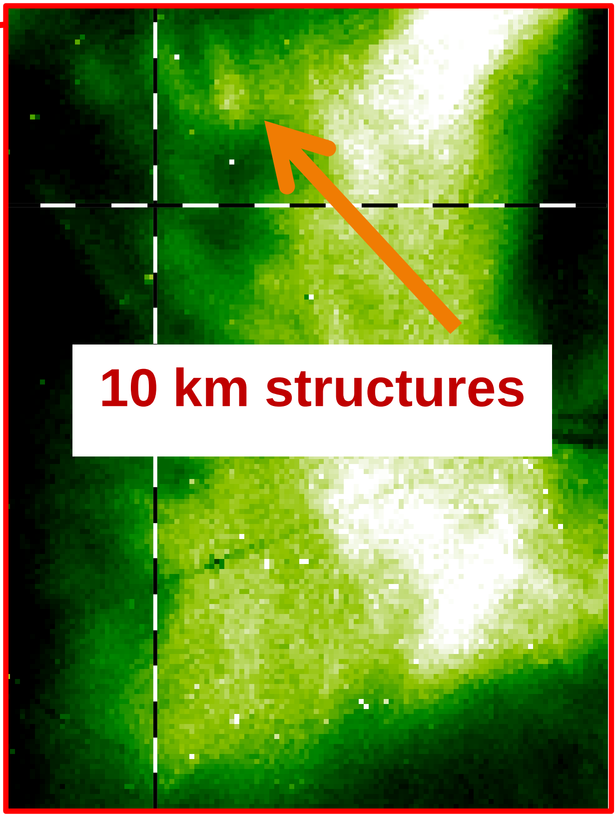
PI: F. Rodrigues, Atmos. Space Tech. Res. Assoc.

2-D Optical Measurements of Ionospheric Irregularities

Complex ionospheric structure leading to GPS error and other system effects observable only by optics

High-sensitivity observations reveal small-scale structures





PI: T. Pedersen, AFRL/RV --- Star Team

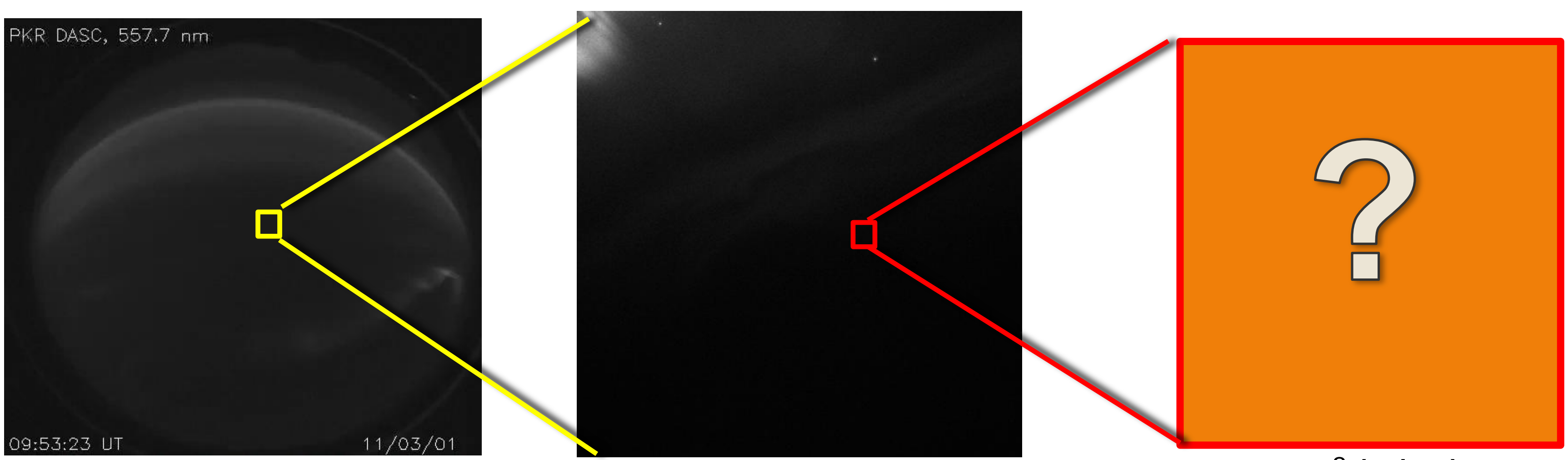
Fortunately, there are several new projects in the works to help address these issues;

these include both new observational techniques or approaches and new modeling studies

Resolving the finest scales in the aurora

The aurora exhibits a vast hierarchy of scales with the finest scales of variability associated with filamentary current systems and ionospheric turbulence, which affect wave propagation at HF, VHF, and UHF.

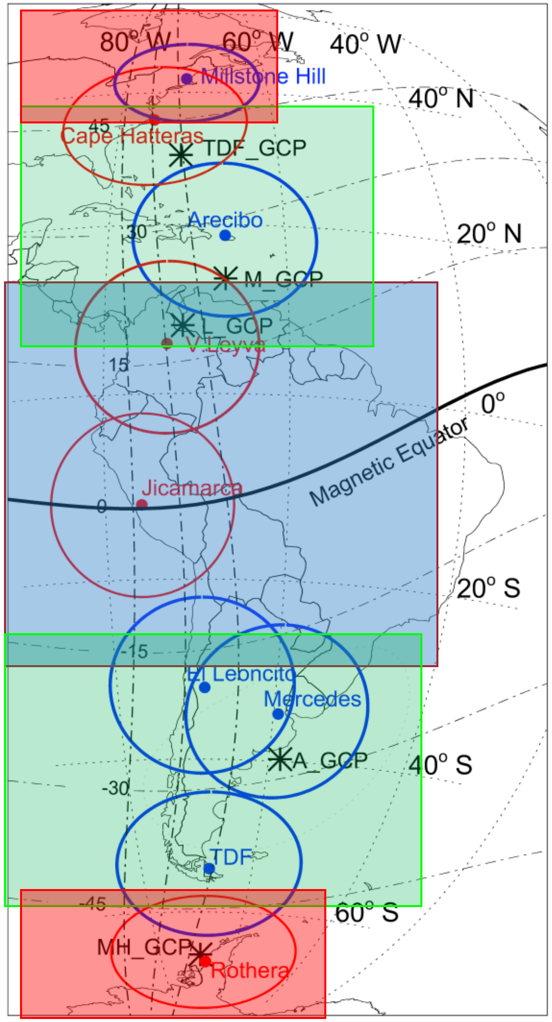
This research will exploit high-speed CMOS imaging technology, coupled with improved image intensification technology, with the goal of fully resolving dynamic aurora.



180^{o} (500 km) 9^{o} (16 km) 1^{o} (2 km)

PI: J. Semeter, Boston U.

THE DURIP OPTICAL NETWORK
A longitude chain of imagers



A chain of all-sky imagers near 70° W, extending pole to pole, and able to study conjugate processes for the first time

1. Equatorial and low latitude Ionosphere
From magnetic equator to mag lat
Effects on trans-ionospheric radio signals using GPS and optical diagnosis.

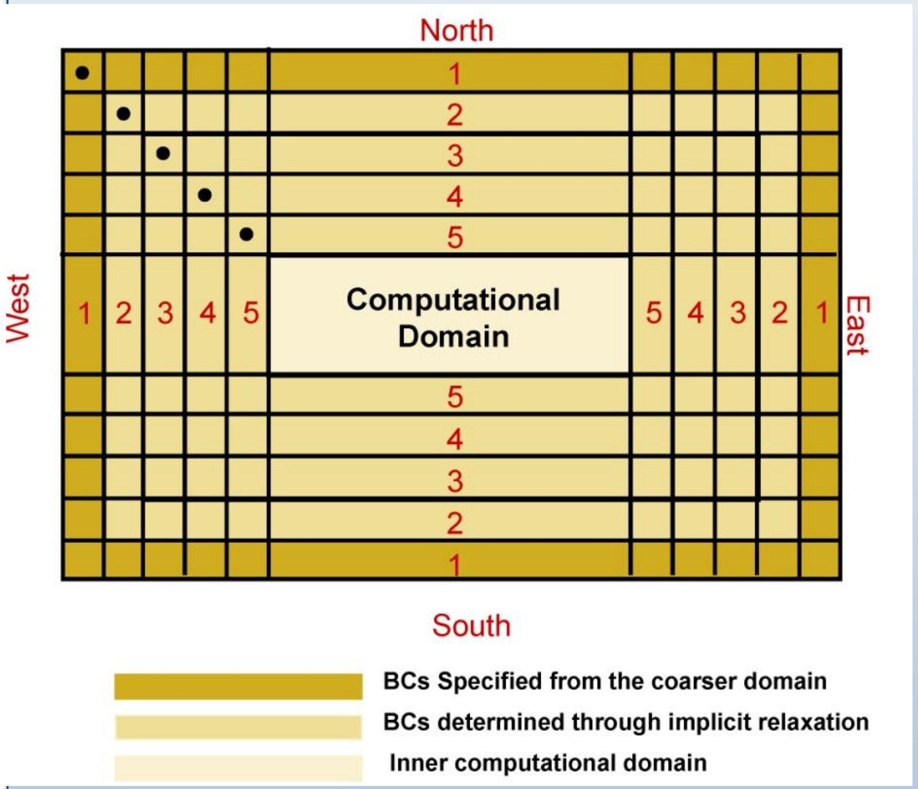
2. Mid latitude Ionosphere
Poleward from ~ ± 20 to ~ ± 40 mag lat.
Nighttime MSTIDs, coupling of E and F regions

3. Sub-auroral Ionosphere
Antarctic peninsula and the Northern US.
Stable auroral red arcs

PI: M. Mendillo, Boston U

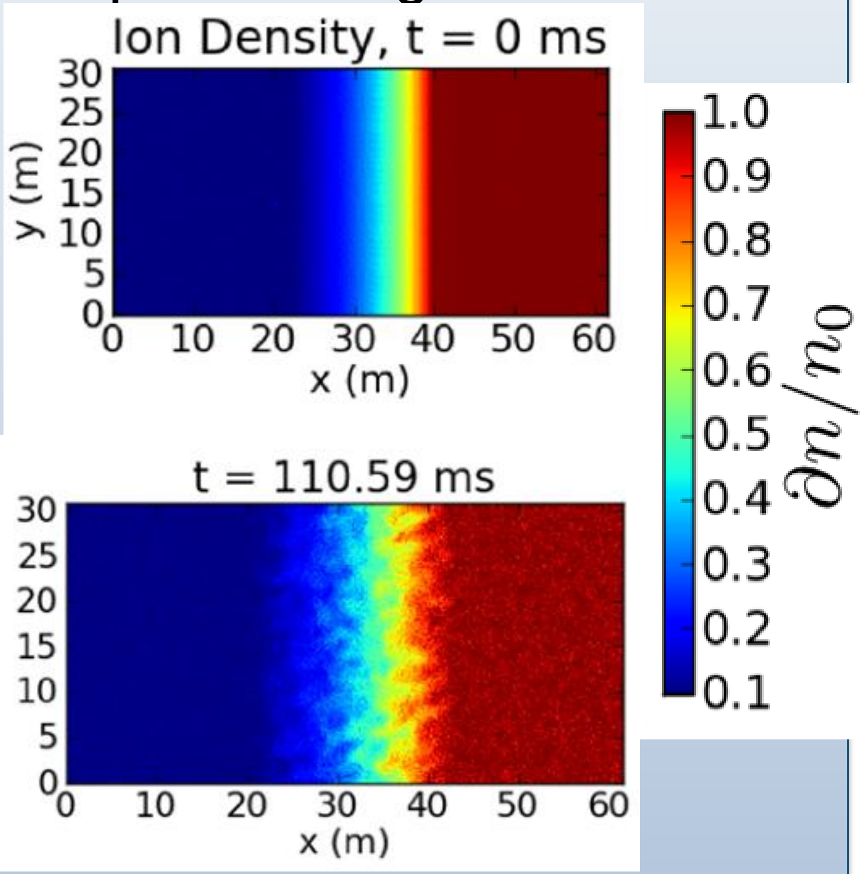
New Modeling Developments

Multiscale modeling of ionosopheric dynamics



PI: A. Mahalov, Arizona State U

Simulations of small-scale ionospheric irregularities

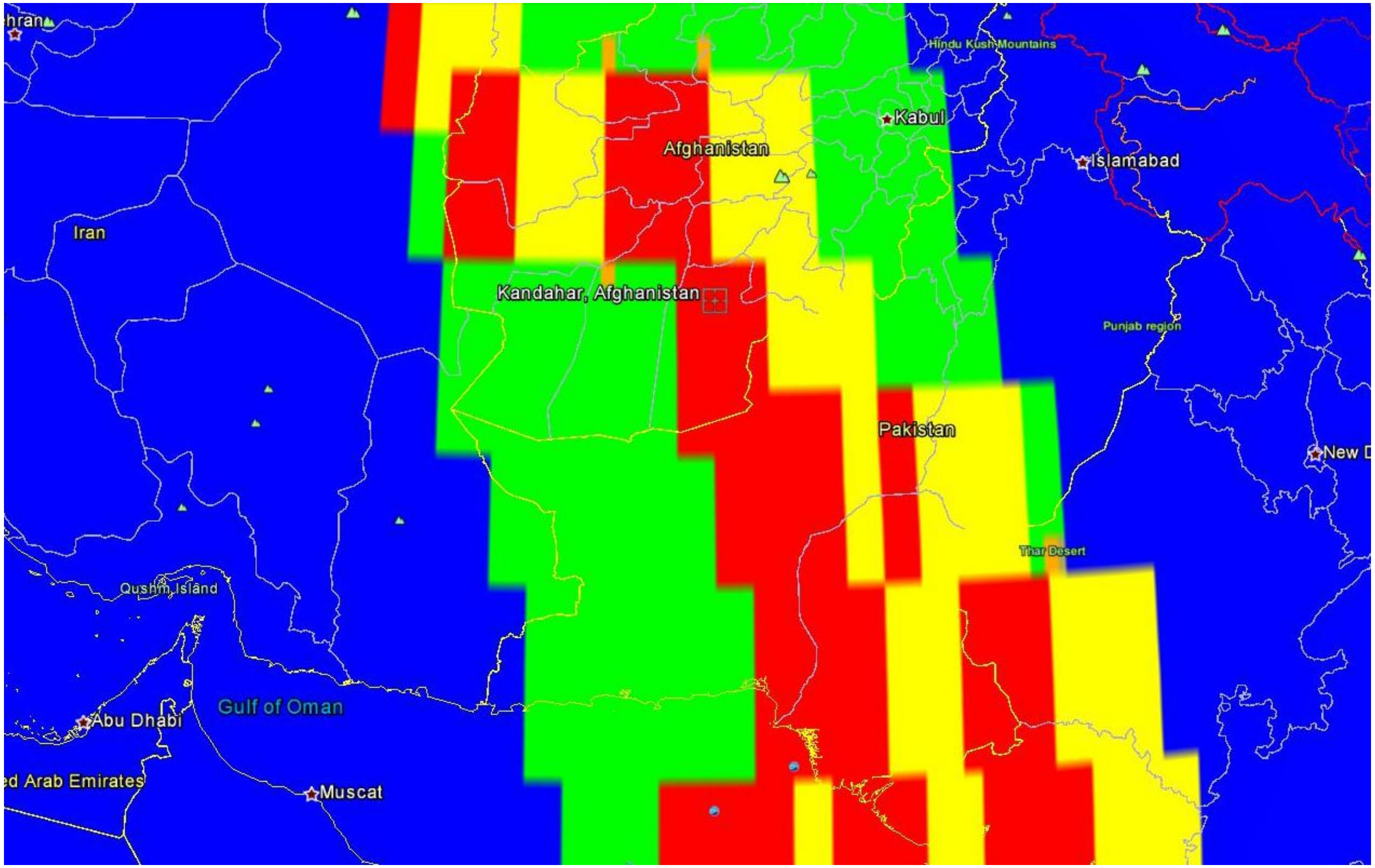


PI: M. Oppenheim, Boston U.

All of which aims to lead to ….

Scintillation Prototype

Experimental daily scintillation maps



Scintillation Region
Future Scintillation
Quiet Region
No Data

YIP PI: J. Comberiate, Johns Hopkins U

Now turning to neutral atmosphere/satellite drag

NADIR: Neutral Atmosphere Density Interdisciplinary Research

U Colorado

USAFA

Focus Areas:

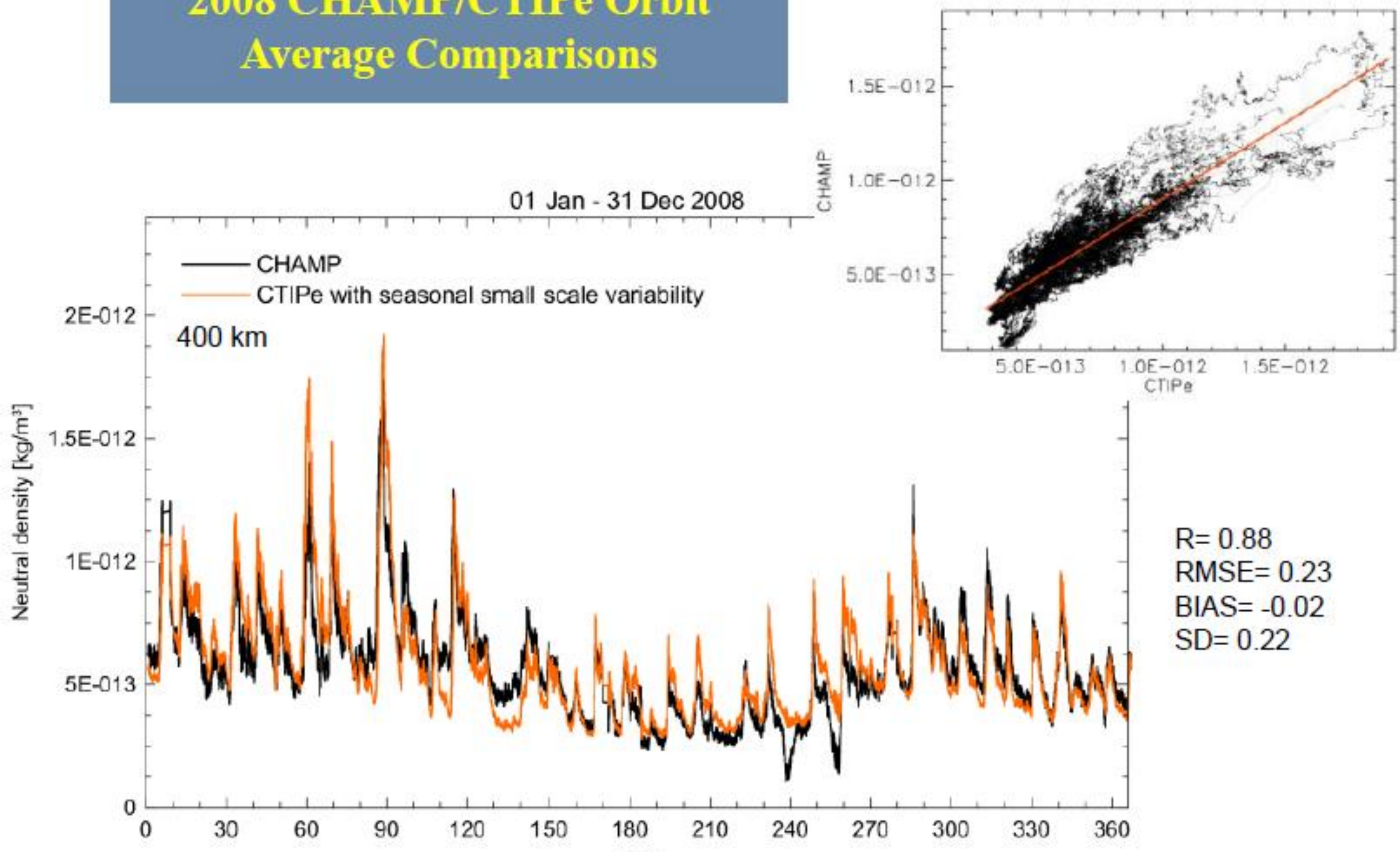
I. Scales of Density Variability, Winds, and Drag Prediction
II. Internal Processes and Thermosphere-Ionosphere Coupling
III. Energy Partitioning at High latitudes and Density Implications
IV. Wave Forcing from the Lower Atmosphere
V. Forecasting Geomagnetic Activity
VI. Forecasting Solar EUV/UV Radiation
VII. Driver-Response Relationships
VIII. Satellite Drag in the Re-entry Region

University of New Hampshire

The University of Alabama

Modeling the neutral density: comparison with satellite data

2008 CHAMP/CTIPe Orbit Average Comparisons

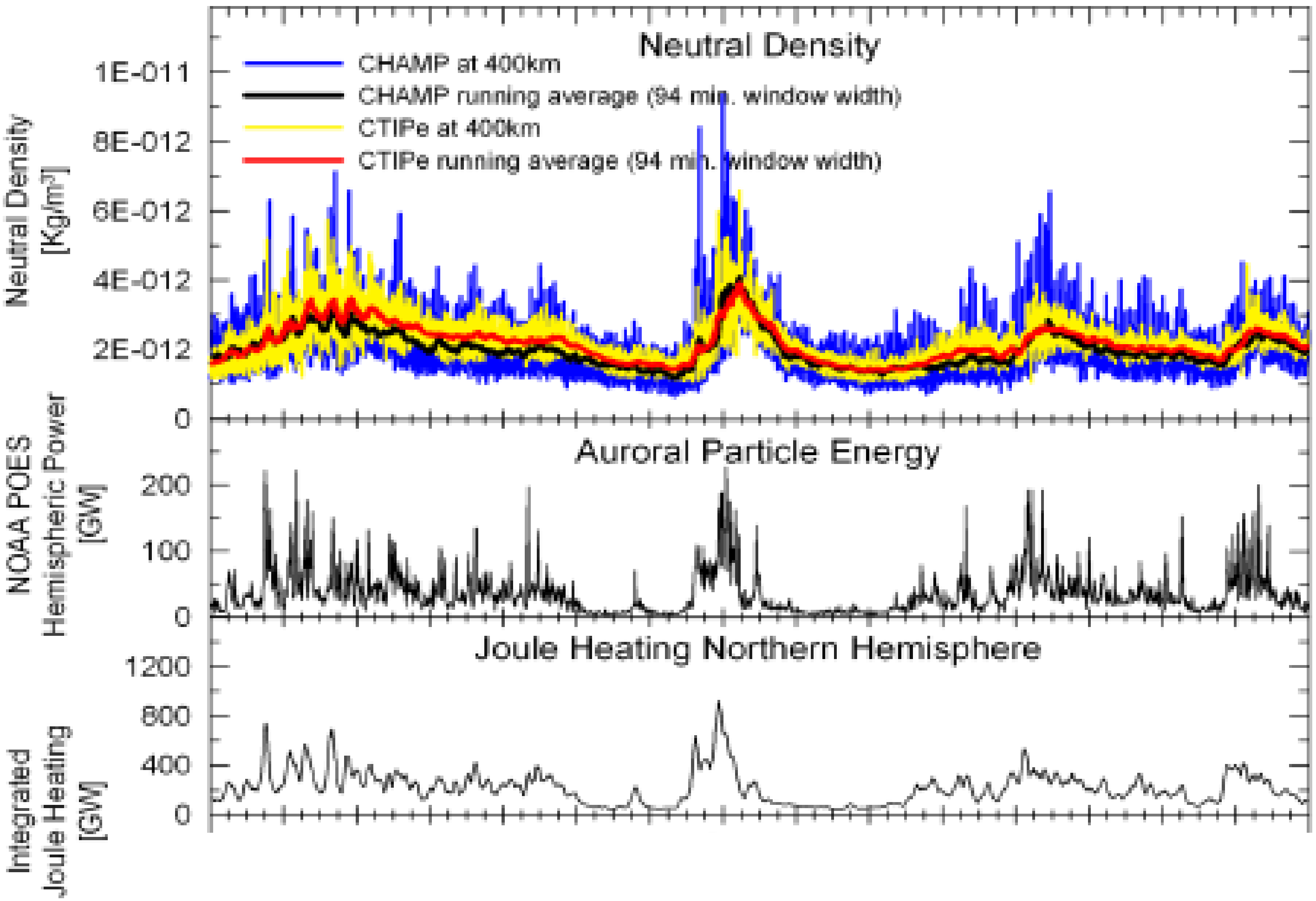


PI: M. Fedrizzi, U Colorado

A Key to Improved Agreement

Small scale structures!

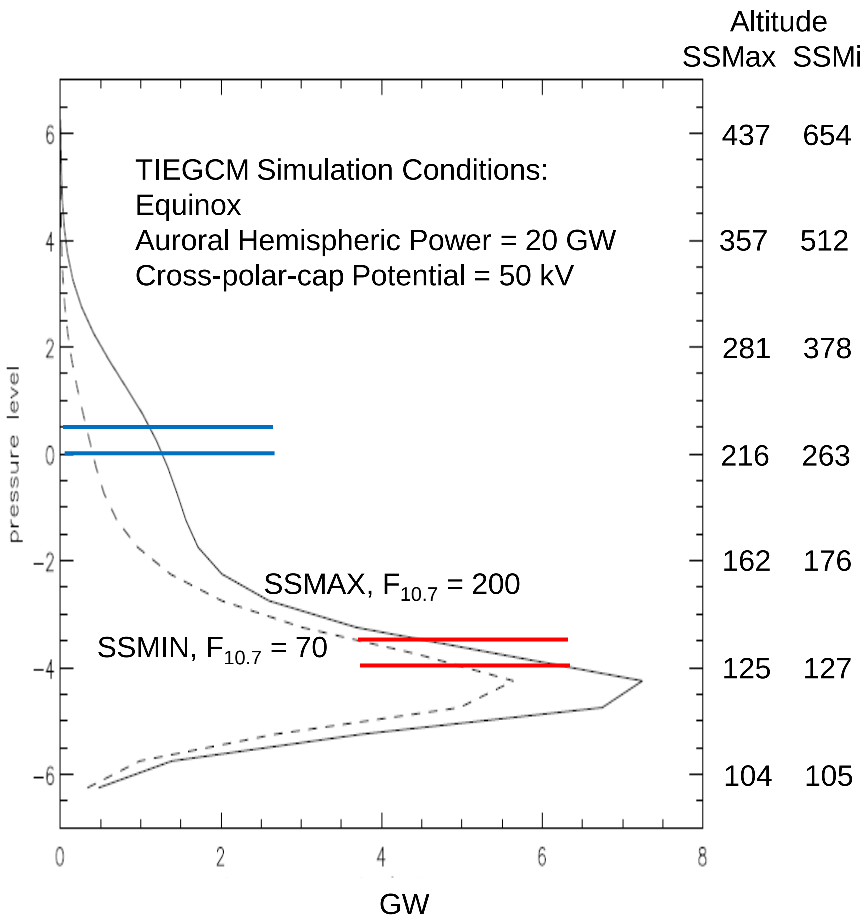
In particular, the seasonal variation in the small scale electric field

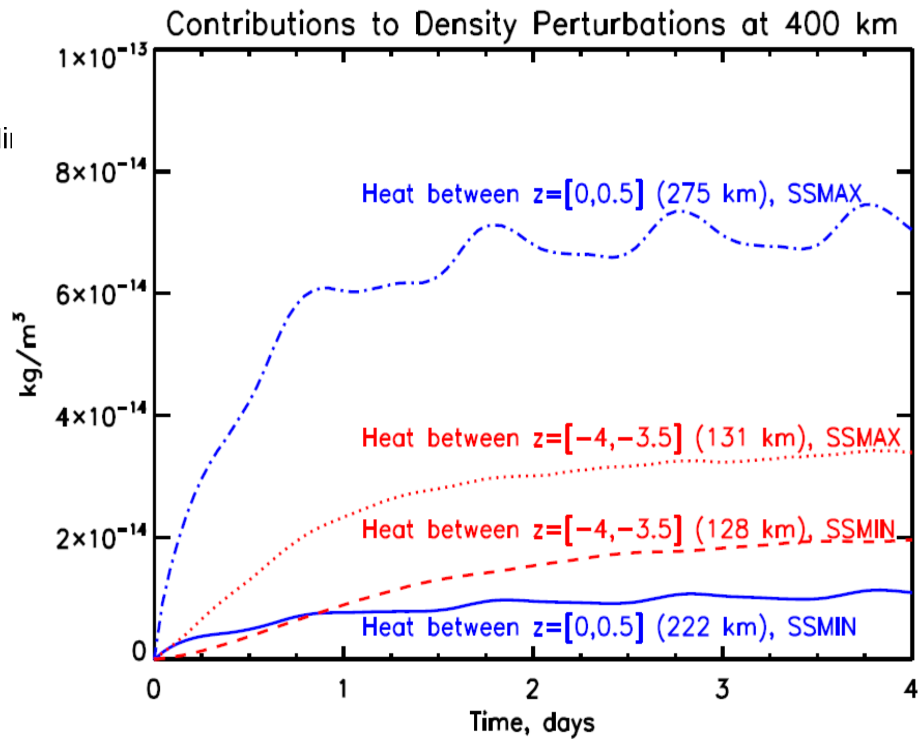


PI: M. Fedrizzi, U Colorado

Density Response to Joule Heating at Different Heights

Globally Integrated Joule Heating Per Half Scale Height

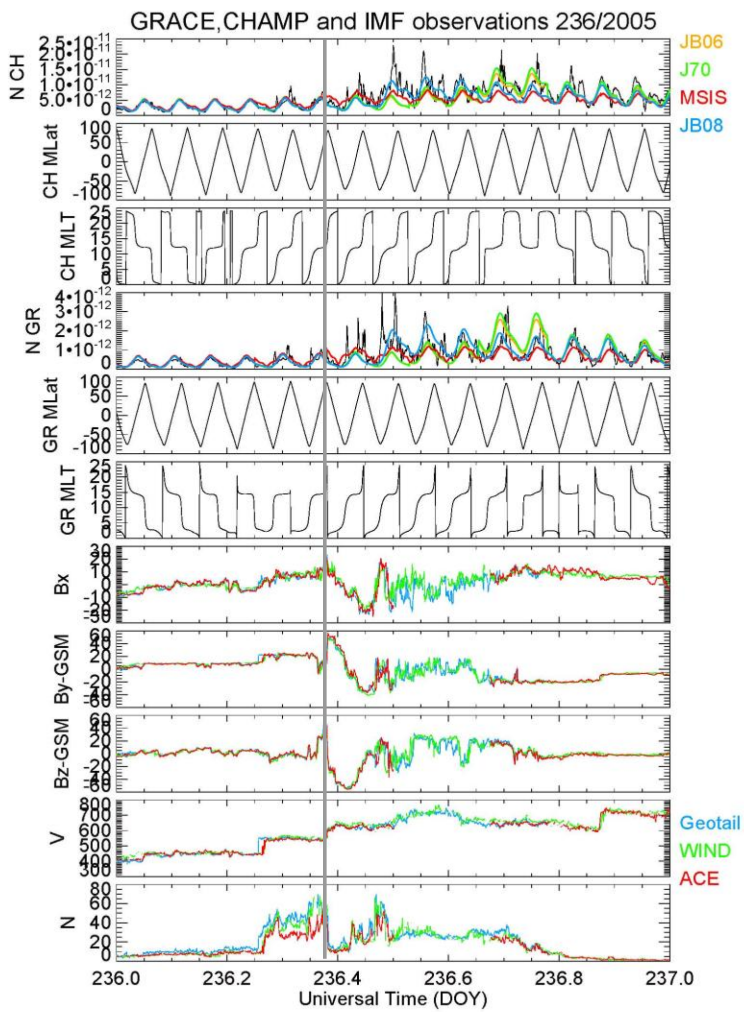


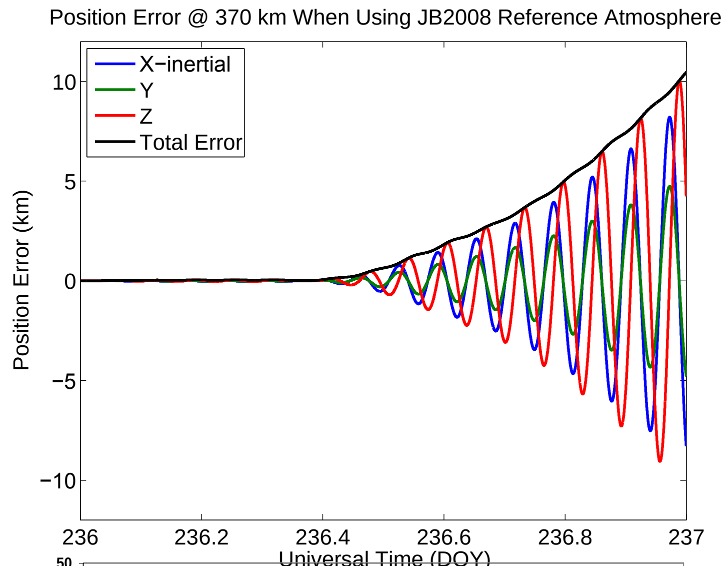


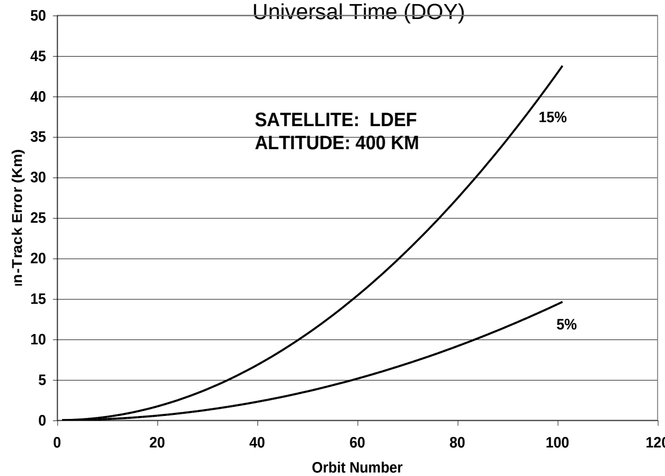
Much more Joule heat is deposited in the E region than in the F region, but F-region heating dominates the density response during at least the first 12 hours of a storm, especially at solar maximum. This has important implications for modeling the density response.

PI: A. Richmond, NCAR

Investigating the effects of energy input to the M-I-T* system



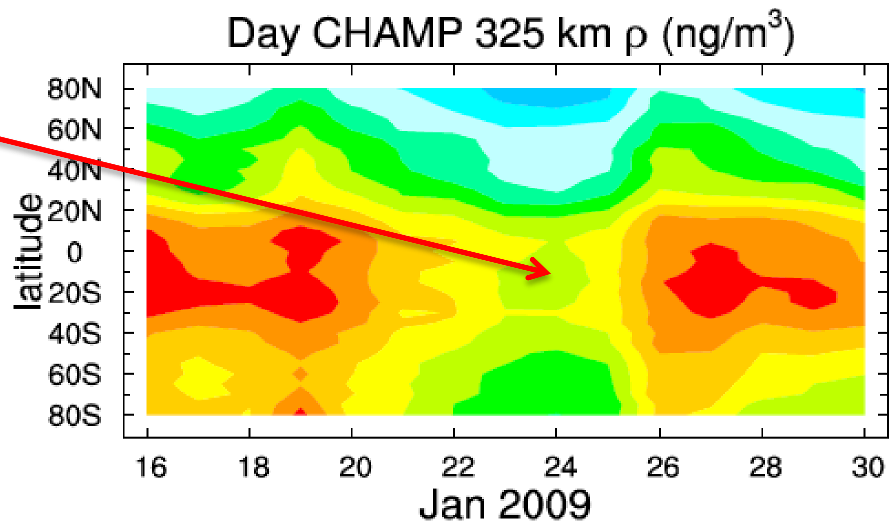




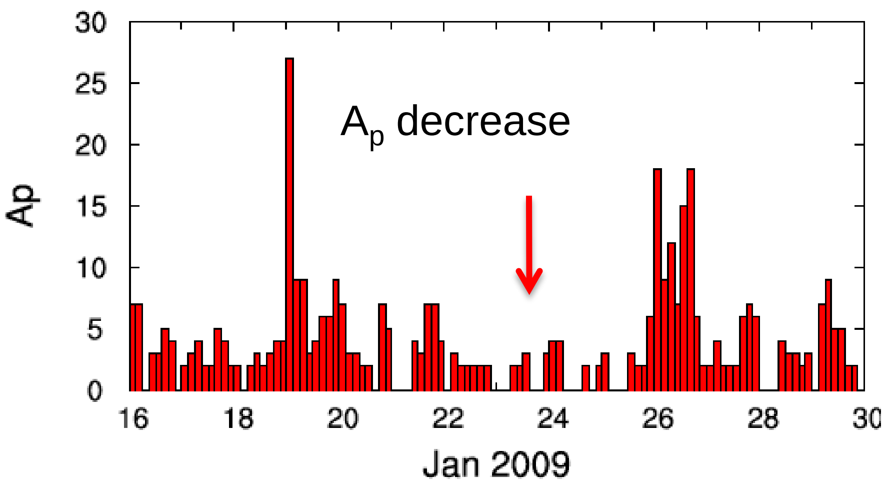
PI : E. Zesta, AFRL/RV *** M-I-T: magnetosphere-ionosphere-thermosphere**

Neutral Density Response to the 2009 Sudden Stratospheric Warming

A significant drop (30%) in neutral density occurred during the SSW, accompanied by a reduction in satellite drag on the CHAMP satellite.

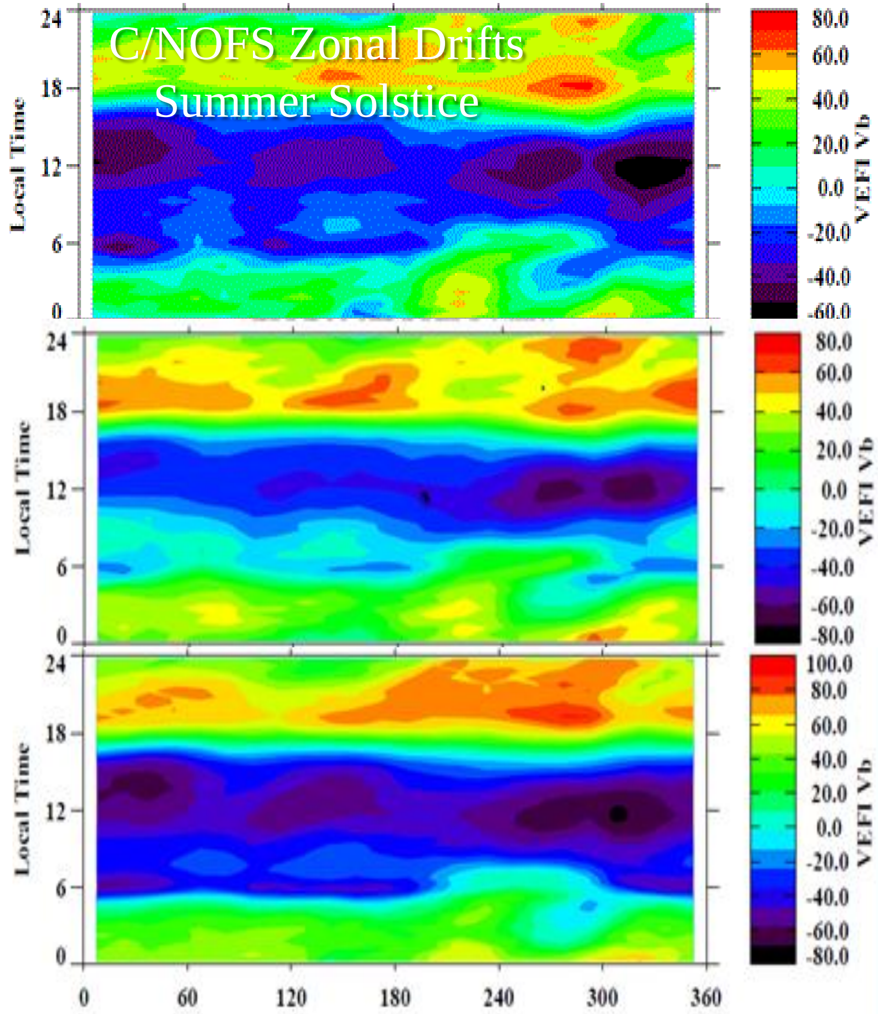


Careful analysis revealed the cause to be magnetic activity. The NADIR model CTIPe was able to simulate the response with high accuracy.

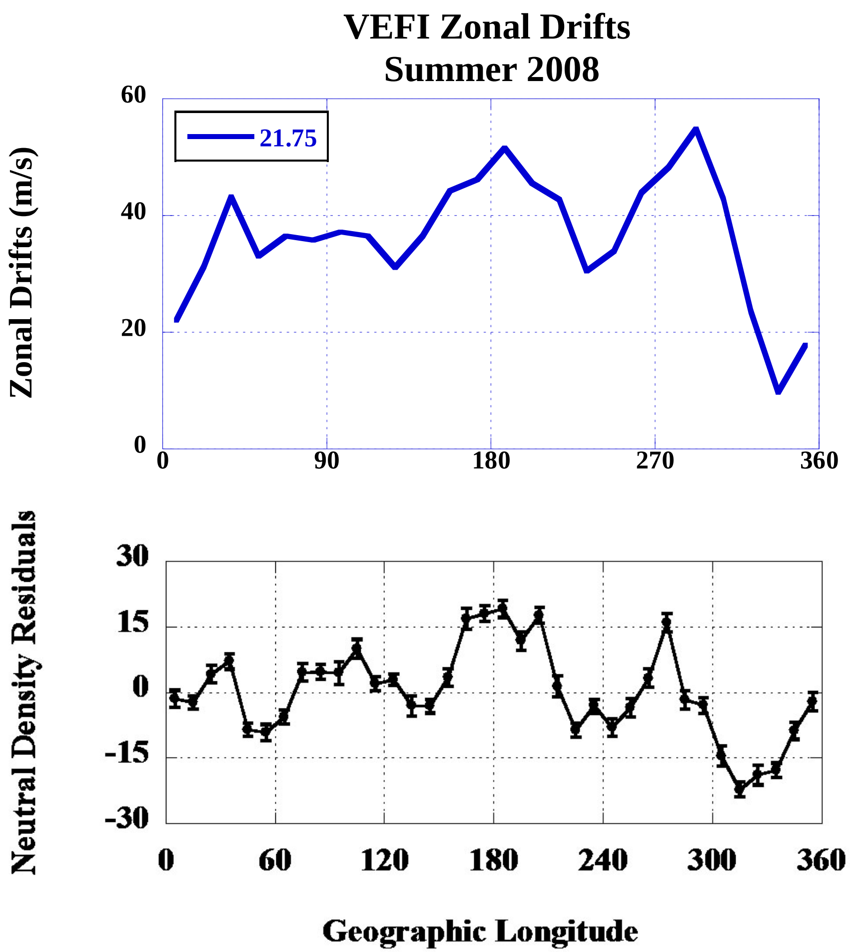


PI: T. Fuller-Rowell, U Colorado

Wave Structures observed in other fields



PI: R. Pfaff, NASA/GSFC



PI: C. Huang, AFRL/RV

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Wrap Up: Trends / Emphasis

Focus on projects that enable predictive capabilities for

* solar activity
* neutral thermospheric densities
* scintillations and ionospheric irregularities

Maintain projects investigating the radiations belts

Current thermosphere/ionosphere projects that do not address neutral densities or ionospheric scintillations may not be renewed.

(Some) Challenges to Progress in Space Sciences

Challenge	Opportunity?	Pursuing?
Construction of “Sun to mud” predictive model	Need for such a model is obvious. However, cross-scale coupling is a huge challenge. Funding is difficult, particularly in current climate.	Discussions with other agencies and community leaders.
Predicting solar eruptive events (flares and CMEs)	STEREO, Hinode, and SDO are providing extensive datasets and new insights. Assimilative models are evolving, complemented by numerical MHD models and lab investigations.	About 1/3 of portfolio is invested in solar physics, with strong ties with personnel in RV. Ongoing collaboration with the National Solar Observatory.

(Some) Challenges to Progress in Space Sciences

Challenge	Opportunity?	Pursuing?
Predicting ionospheric irregularities.	C/NOFS plus GPS and TEC databases are providing much new information and opportunities for assimilative models. Advances in computation and identification of important physical processes such as gravity waves are contributing much to the goal.	Discussions with other agency representatives are ongoing, particularly with NSF and NOAA/SWPC.
Forecasting neutral densities 1-3 days ahead	Recent satellites CHAMP, GRACE, and RAIDS are providing extensive datasets on neutral densities*	FY07 MURI is in final year. Significant contributions in solar activity effects, wave effects, drag coefficients. Transitioning results in collaboration with RVB.
Coupling thermosphere/ ionosphere to magnetosphere	Has not achieved high visibility or critical mass. Limited funding .	Minor; through individual PIs. NSF leads on this topic; collaborate with them.

Contacts in Other Funding Agencies

Agency	POC	Science Area
NSF	Rich Behnke et al.	Solar/Terrestrial Relations, Magnetospheric Physics, Aeronomy, Cubesats
ONR	Scott Budzien	Neutral atmosphere and ionosphere
NOAA	~~Tom Bogdan~~	Space Weather predictions
NASA	Madhulika Guhathakurta	Heliophysics (Sun to Earth)
NRO	Dave Byers	Remote sensing of the geospace environment

Thank you for your attendance and your attention!